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Superobbing Satellite Winds for NAVDAS

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14. ABSTRACT
This report presents the results from a series of tests on the superobbing strategy for satellite-derived winds in NAVDAS (NRL Atmospheric Variational Data Assimilation System). A description of feature-track wind and SSM/I windspeed and precipitable water data is presented, followed by a description of the tests and their results. The final section in the report presents recommendations about which of the tested aspects of the superobbing strategy should be implemented. The recommended configuration uses 2°E prisms of roughly equal area rather than 2°E latitude-longitude boxes, a constraint based on wind direction as well as u and v components, no time averaging, duplicate checking, prism quartering in regions of significant shear, outlier checking for one and two outliers, and a speed criterion of 7 m/s.

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Contents

1. Introduction

Neighboring high-density satellite winds tend to be highly correlated horizontally. Appropriately superobbing satellite winds can preserve most of the variability present in these observations while reducing the degree of horizontal correlation and reducing the number of single-level observations to process. This paper discusses the manner in which satellite winds are averaged into "superobs" in NAVDAS (NRL Atmospheric Variational Data Assimilation System). Results from a series of tests of different aspects of the NAVDAS satellite wind superobbing strategy are also presented, using data from the six-hour time window centered on 1200 UTC 29 April 2002. The data and individual tests are described in sections 2 and 3 of this paper, respectively, the results are compared in section 4, and changes to NAVDAS and future work are proposed in the final section.

2. Data

Two basic types of satellite wind data are currently used in NAVDAS–SSM/I windspeeds and feature-track winds. Estimates of surface windspeed are derived from the Special Sensor Microwave Imager (SSM/I) flown on the polar-orbiting Defense Meteorological Satellite program (DMSP) satellites. These data are processed at Fleet Numerical Meteorology and Oceanography Center (FNMOC), with a typical data distribution shown in Fig. 1.

Feature-track winds are processed at the University of Wisconsin (UW) Cooperative Institute for Meteorological Satellite Studies (CIMSS), the U.S. Air Force Weather Agency (AFWA), the National Environmental Satellite, Data, and Information Service (NESDIS), the European Meteorological Satellite Organization (EUMETSAT), and the Japan Meteorological Agency (JMA). All five centers use a similar technique based on geostationary satellite imagery in visible (VIS), infrared (IR), or water-vapor (WV) channels. Figure 2 shows a typical data distribution for UW winds, which are processed from five satellites–GOES-8, GOES-10, Meteosat-5, Meteosat-7, and GMS-5. AFWA feature-track winds are

generated using the UW software for Meteosat-5, Meteosat-7, and GMS-5 and used in NAVDAS in place of the UW winds for these satellites; in the dataset used for these tests, both AFWA and UW winds are labeled UW, a problem that has since been corrected. Figure 3 shows a typical data distribution for NESDIS winds, which are processed only from GOES-8 and GOES-10, and JMA winds, which are processed only from GMS-5. Note that the UW (or AFWA) and NESDIS winds are much denser than the JMA winds, as a result of the feature-selection methodology used. Finally, a typical data distribution for EUMETSAT winds is shown in Figure 4. The EUMETSAT winds are generated on a fixed grid and so are also less dense than UW and NESDIS winds.

Several varieties of water vapor winds are available. UW produces water vapor winds from three different channels. Winds from the 6.7 µm channel are simply labeled “WV” winds, while winds derived from sounder channels 10 and 11 are labeled “WV10" and “WV11", respectively. Since the number of WV10 and WV11 winds are small, they are not discussed in detail in this paper. NESDIS, EUMETSAT, and JMA all produce water vapor winds labeled cloudy air (“WVCLD”), while only EUMETSAT produces water vapor winds labeled clear air (“WVCLR”).

Prior to superobbing, satellite winds are decoded from the FNMOC internal formats and placed in the NAVDAS innovation vector format. In NAVDAS, innovations are defined as observation minus background values at observation locations, so interpolating the time-interpolated background forecast to observation locations is part of defining the innovation vector.

3. Superob tests

Details of the various tests in superob strategy are presented here. All tests used the same vertical partitioning, namely fixed 50 mb layers centered on pressure levels extending every 50 mb from 1000 mb to 100 mb for a total of 19 layers. A one-hour time constraint is placed on SSM/I observations, requiring them to be from the same swath. However, no time constraint is placed on

feature-track winds in the initial tests; using such a time constraint is one of the options tested.

All tests also used the same preliminary data quality screening. All observations missing latitude, longitude, pressure, time, or a background value are rejected, as are observations with pressures below 1025 mb or above 100 mb and wind vector observations missing either the u or v component. Limits are also placed on the magnitude of the u and v innovations, with the threshold varying as a function of pressure from 8 to 13 m/s for feature-track winds and varying as a function of windspeed from 3 to 10 m/s for SSM/I windspeeds. Feature-track winds with speeds less than 3 m/s are rejected here, as are SSM/I observations at possible ice points and those with accuracy flags greater than zero (possible rain points).

An underlying assumption in this code is that neighboring satellite winds from a particular sensor and satellite are similar and so can be averaged together without a significant loss of information. Conversely, different sensors, satellites, and even processing centers may yield winds that have different characteristics. Therefore, superobs are formed separately for different sensors, satellites, and processing centers. Furthermore, observed windspeeds are required to be within 5 m/s as are both the u and v components of the wind in order for a superob to be formed. If three (five) or more observations are present, one (two) may be rejected as an outlier in order to meet these criteria. A minimum of two observations for feature-track winds (three for SSM/I windspeeds) is also required to form a superob. An exception is made for EUMETSAT feature-track winds, which are quality-controlled to ensure horizontal and vertical consistency. Single EUMETSAT winds are passed through as superobs.

While these criteria are imposed on the observed speed, u, and v, the superob itself is defined in terms of the average u and v innovations for feature-track winds and average speed innovation for SSM/I windspeeds. Other

quantities in the innovation vector such as pressure are also averaged, with horizontal position being the exception. The location of the superob is defined as the latitude and longitude that minimizes the great-circle distances to the individual observations and is computed using an algorithm developed by Dr. Roger Daley.

a) Test 1: Old superob code

The first version of the superob code (currently running in NAVDAS) averages satellite winds on a 2E latitude-longitude grid. In order to mitigate problems associated with the convergence of the meridians, the horizontal averaging examines all observations in a given layer within 160 km of the center of the 2E superob box. As a result of the overlap between neighboring superob boxes, a given observation can be used in more than one superob. In order to avoid needless duplication, superobs are required to include at least one observation that has not been used previously. Furthermore, the position of the superob is required to be within 110 km of the center of the 2E superob box to be valid. It is assumed that the observations in superobs that violate this constraint are better utilized in neighboring superobs, although some might not be used at all.

b) Test 2: Prism superob code

An alternate strategy for distributing superobs horizontally was devised by Dr. Edward Barker for ATOVS sounding data. In this strategy, 2E latitude bands are divided into an integer number of “prisms” that are roughly square in terms of distance along each side. Therefore, 2E latitude bands adjacent to the equator have 180 prisms, while the latitude band centered at 89E has only 7 prisms. In this strategy, observations are not used in multiple superobs, and no constraint is imposed on the position of the superob with respect to the center of the prism.

c) Test 3: Alternate direction-based criterion

This test used the prism version of the code with a modified constraint on which groups of observations qualify as superobs. Observed windspeeds are still required to agree within 5 m/s to form a superob. However in this test, the u and v components are allowed to vary by more than 5 m/s if the wind directions are within 20E, excluding 1 or 2 outliers if necessary. This test allowed some higher-speed superobs to be formed that were rejected by the 5 m/s u-v threshold.

d) Test 4: No time averaging

The previous tests applied a time criterion to SSM/I windspeeds, but did not for feature-track winds. This test therefore only superobs feature-track winds having the same time. It uses the prism version of the code that is otherwise the same as in Test 3.

e) Test 5: Duplicate checking

In the course of checking the performance of the superob code, it was found that duplicate observations are present, primarily in UW feature-track winds. A duplicate checker was therefore implemented which searches for exact duplicates only. An exact duplicate is found if the platform identifier, time, pressure, location, and observation are identical. For feature-track winds, both the u and v component winds must be identical; for SSM/I data, only the windspeeds are required to be identical. The test of duplicate checking was performed with the prism version of the code otherwise the same as in Test 4.

f) Test 6: Kinetic energy adjustment

Averaging u and v components to form a superob can result in the loss of kinetic energy (KE) if the wind directions vary significantly. While the criteria imposed on u, v, and direction mitigate this problem, they do not entirely

remove it. Therefore a test was made to restore the lost kinetic energy. In the algorithm used, the average values of u and v are used to define the wind direction for both the observation and background fields. This direction is coupled with the average wind speed to define adjusted u and v values that are consistent with the average speed. The adjusted innovation is then defined as the difference between the adjusted observation and the adjusted background. In most cases, the adjustment is less than 0.2 m/s, but it can occasionally be larger. This test was performed with the prism version of the code otherwise the same as in Test 5.

g) Test 7: Prism quartering

At times, there is too much variability in the observations in a given prism to meet the criteria to form a superob. In these cases, the prism is divided into four sub-prisms according to the location of the center of the prism, and the observations in each sub-prism are examined to see if they meet the criteria to form a superob. This algorithm allows some smaller-scale features to be captured by the superobs where the data are able to meet the criteria. Only prisms with a minimum of five observations are allowed to be quartered. This test was performed using the prism code.

h) Test 8: No two-outlier checking

Innovation statistics for superobs that were formed after two outliers were rejected are similar to those for "bad" superobs–those that failed to meet the criteria. This test omits checking for two outliers and instead tries prism quartering for those cases.

i) Test 9: Increased speed criterion

An inconsistency is present in requiring the speed, u, and v values of the observations to all be within 5 m/s. If the u and v values both vary by exactly 5

m/s, the speed values could vary by as much as 7.1 m/s. Therefore a test was made in which the speed criterion applied to feature-track winds was changed to 7 m/s, while the 5 m/s (or 20E) criterion was still applied to u and v values (or direction). This test was performed using the prism code otherwise the same as in Test 8.

j) Test 10: Low-accuracy SSM/I observations

The final test admitted low-accuracy SSM/I windspeeds. This test used the code that was otherwise the same as that used in Test 9. However, the increased speed criterion and KE adjustment were not applied to SSM/I data, and no SSM/I duplicates were present, so duplicate checking had no effect.

4. Results

The results from the tests are examined separately for each sensor/channel, with data from the various satellites averaged together. In order to avoid large fluctuations that obscure overall trends, statistics for fewer than 50 superobs in a particular category are omitted from most of the figures. In counting observations and superobs, a feature-track wind vector is counted as one observation (or superob) as is an SSM/I windspeed.

a) Old superobbing strategy (Test 1)

Before examining the results from the various tests using the prism code, the results from Test 1, which used the old superob code, are presented in detail.

Table 1 gives an overview of the data for the 1200 UTC 29 April 2002 (2002042912) dataset, which includes the data for a six-hour window centered on the specified time. The statistics are broken down by data type, with a listing also given of the processing centers that produced each data type present in the 2002042912 dataset. A total of 183,990 observations are present in this dataset. Out of these, 115,808 (63%) are used to make 21,918 superobs in Test 1, a reduction in the data volume of nearly 90%. The SSM/I data are the most

dense, with the SSM/I surface windspeeds comprising 40% of the observations (and 28% of the superobs). Of the feature-track wind types, IR winds are the most numerous at 28% of the observations (and 37% of the superobs). IR winds make a larger percentage of the superobs than SSM/I windspeeds because SSM/I windspeeds which are available only at the surface. The various types of water vapor winds comprise 20% of the observations (and 24% of the superobs), while VIS winds comprise 12% of the observations (and 11% of the superobs).

Innovation statistics are also listed in Table 1 for each data type. The average speed innovation ("AVG") gives a measure of the relative bias in the observations compared to the background field. Most types in the list have a small bias in the observations. Notable exceptions are the VIS winds, which have a bias of 0.6 m/s, and WVCLD winds, which have a bias of -0.5 m/s. This reflects the tendency for feature-track winds to overestimate low-level windspeeds, perhaps a result of either height assignment errors or cirrus contamination, and to underestimate upper-level windspeeds, likely a result of either height assignment errors or the relatively large time interval between images that is typically used. The statistics for the WV10 and WV11 winds should not be given much credence because of the small sample size for these two types.

The average magnitude of the speed innovations ("MAG") is listed in Table 1 beneath the average innovation. These show that the low-level data types (SSM/I and VIS) typically have small innovations, while the upper-level data types (WV, WVCLD, WVCLR) typically have larger innovations, with average magnitudes nearly twice as large as the low-level data types.

In general, the superob innovation statistics are smaller than or equal to the observation statistics. For example, the average innovation for IR winds is 0.1 m/s for observations and 0.0 m/s for superobs, while the average innovation magnitude is 2.3 m/s for observations and 2.1 m/s for superobs. This implies that the data that are not used in the superobbing process are "worse" than the

data that are used, in terms of having a larger bias and larger innovation magnitudes. The unused data include single-observation superobs (other than EUMETSAT), observations rejected as outliers, and superobs with too much shear to meet the criteria.

Figure 5 shows a breakdown of the counts, average speed innovations, and average speed innovation magnitudes for both observations and superobs as a function of pressure level. The counts in Fig. 5a portray two peaks in the vertical. A low-level peak exists in both VIS and IR winds at 850 mb associated with low-level cloud features. A second peak exists at upper levels associated with jet-level clouds, with a maximum at 250 mb for IR winds. WV and WVCLD winds have a broad maximum between 350 and 200 mb, while WVCLR winds have a smaller maximum at 400 to 350 mb. Relatively few winds are present from 650 to 500 mb, with only IR winds available in a significant quantity. This figure also depicts the reduction in data volume associated with superobbing the data. The peaks in the superob distribution generally agree in location with the peaks in the observation distribution, but are much smaller in magnitude.

The quality of the superobs is summarized in Figs. 5b and 5c in terms of the innovation statistics. Figure 5b depicts the average innovation, or bias, which has a positive peak at 750 mb for both VIS and IR data that is slightly smaller for the superobs than for the observations. Assuming that the background depicts the winds reasonably well at these levels, the positive bias implies that the observed wind is too strong. This could result from the feature-tracking algorithm in some cases capturing the motion of thin cirrus aloft but seeing the warmer low cloud through the cirrus and so using a low height assignment. At upper levels from approximately 400 mb to 200 mb, the IR and WVCLD winds have a negative bias, indicating that the observed winds are likely too weak, a known problem with feature-track winds. The WVCLR winds have a similar negative bias, but a bit lower–between 450 and 350 mb. Superobs have a larger negative bias than observations in the 600 mb peak for IR winds, in the 300 mb

peak for IR winds, in the 400 mb peak for WVCLR winds, and at 300 mb for WV winds. Thus, forming superobs appears to slightly increase the problem with weak winds aloft.

Figure 5c portrays the average magnitude of the innovations. These magnitudes increase overall, from just over 1 m/s for VIS and IR winds at low levels to approximately 3 m/s for IR and WVCLD winds at upper levels. It is interesting to note that the WV winds aloft have somewhat smaller average magnitudes than the IR winds, while the WVCLR winds have a somewhat larger average magnitude. Superobs have slightly smaller innovation magnitudes than do observations.

The statistics also depend on the manner in which superobs are formed. Figure 6 shows these same statistics for IR winds, broken down in terms of superob type. IR winds were chosen for this comparison since they are available at the most levels and in the greatest numbers of the available data types. Simple superobs, those that meet the criteria without rejecting any outliers, dominate the statistics, with values similar to those for all accepted superobs. While some outliers are found at low levels, the superobs formed after rejecting these outliers have nearly the same average innovation and average innovation magnitude as the simple superobs. Outliers are more of a factor at upper levels, where one-outlier superobs have a greater negative bias (Fig. 6b) and a greater average innovation magnitude (Fig. 6c), which is especially evident at 250 mb.

Isolated observations, defined when a prism has only one observation that is not from EUMETSAT, are not used in NAVDAS and are available in significant numbers at all levels. Note that at mid-levels, isolated observations are available in roughly the same numbers as valid ("all") superobs (Fig. 6a). These isolated observations have a bias that is similar to that for valid superobs, with significant differences only at mid-levels (Fig. 6b). The average innovation magnitude for isolated observations is slightly larger than that for valid superobs

are nearly all levels (Fig. 6c). So-called bad superobs are those that fail to meet the superob criteria. They occur primarily aloft and have comparatively large negative biases from 300 to 200 mb and a large positive bias at 150 mb (Fig. 6b). The average innovation magnitudes for these bad superobs are similar to those for valid superobs, except at 150 mb where the bad superobs have larger average innovation magnitudes than do valid superobs (Fig. 6c).

The characteristics of the superobs are also a function of the number of observations per superob. Figure 7 portrays the same statistics as Figure 6, comparing the various types of superobs for IR feature-track winds. The top panel shows that over 80% of IR superobs were formed from 6 or fewer observations, with the majority being simple superobs. The center panel shows that the speed bias does not appear to be a function of the number of observations per superob. However, the one and two outlier superobs as well as the bad superobs have a more negative bias than the simple superobs, which have a slightly positive bias. This likely results from the fact that simple superobs are available in the greatest numbers at lower levels, while the one- and two-outlier superobs and bad superobs are available in the greatest numbers at upper levels (Fig. 6a). The average speed innovation magnitude does appear to be a function of the number of observations per superob, with one-ob superobs having an average magnitude of nearly 3.0 m/s, decreasing to 1.5 m/s or less for superobs having 7 or more observations per superob. In addition, the one and two outlier superobs and the bad superobs also have larger average magnitudes than the simple superobs, again likely a result from them portraying the larger values that occur aloft. It is also interesting to note that the EUMETSAT one-ob superobs, which are accepted, have very similar average magnitudes to the other one-ob superobs, which are rejected, suggesting that the handling of one-ob superobs should be investigated further.

Finally, Figure 8 portrays these same statistics as a function of latitude. The counts in Fig. 8a show that IR and WVCLD superobs have a maximum in the

tropics, while SSM/I, VIS, WVCLR, and to some extent WV superobs have a minimum in the tropics and maxima in the subtropics. The counts tail off at higher latitudes in both the Northern and Southern Hemispheres. The average innovations in Fig. 8b portray a positive bias for IR and WVCLD superobs in the tropics, a positive bias for VIS superobs in the subtropics where the SSM/I speed superobs also have a positive bias, and a negative bias for IR and SSM/I superobs in mid-latitudes.

It is interesting to note that the negative bias for IR winds in mid-latitudes is much stronger in the Northern Hemisphere. This may reflect the particular synoptic situation in this dataset, but it is more likely a result of the greater availability of high-quality rawinsonde and aircraft winds yielding a more accurate background field in the Northern Hemisphere, which would make the underestimation of the windspeeds aloft by the satellite winds more apparent. A negative maximum in WV superobs is also seen in the Northern Hemisphere, perhaps for the same reason.

Finally, Figure 8c shows a tendency for SSM/I speed superobs to have an average innovation magnitude of roughly 1 m/s in the tropics, increasing to roughly 1.5 m/s in midlatitudes. VIS winds have an average innovation magnitude of 1 to 2 m/s in the subtropics, while IR winds have average innovations that are generally less than 2 m/s in the Southern Hemisphere and generally greater than 2 m/s in the Northern Hemisphere. WV and WVCLD superobs have average innovation magnitudes that are somewhat larger than the IR values at the same latitudes.

b) Prism superob code (Test 1 vs. Test 2)

This comparison focuses on the horizontal partitioning of the data. Test 1 uses overlapping 2E latitude-longitude boxes, while Test 2 uses non-overlapping 2E prisms. Of the 183,990 total observations, 115,808 (63%) are used to make 21,918 superobs in Test 1, and 130,548 (71%) are used to make 29,698 superobs in

Test 2. The superob counts for these two tests are detailed in Table 2 for the various data types. The prism scheme led to 23% more SSM/I windspeed superobs, 60% more VIS superobs, 27% more IR superobs, 38% more WV superobs, 65% more WVCLD superobs, and 56% more WVCLR superobs. Only a slight degradation in innovation statistics is seen, with average innovations and average innovation magnitudes generally agreeing within 0.1 m/s. The most notable exception is WV10, which has the fewest number of observations and superobs.

The quantity and quality of the superobs in these two tests are summarized as a function of pressure level in Fig. 9. The increase in the number of superobs associated with the prism scheme can be seen in Fig. 9a for all levels and data types except the IR winds at mid-levels. The SSM/I speed counts are too large to appear on this scale. Figure 9b portrays little difference in average speed innovation between the two tests for the IR data below 700 mb and for the VIS data below 800 mb. However, Test 2 VIS superobs do have a slightly larger positive bias above 800 mb. At mid-levels, Test 2 yields IR superobs with a small positive bias at most levels, in contrast to the relatively large negative peak at 600 mb in Test 1. For the upper-level winds, the Test 2 innovations generally have a smaller bias than the Test 1 innovations, with the exception of WVCLD and WVCLR superobs.

Figure 9c portrays the average magnitude of the innovations. Below 700 mb and above 400 mb (except for WVCLD superobs), only small differences are present between the two tests. Larger differences between the two tests are present in the IR magnitudes between 500 and 400 mb and in the WVCLR magnitudes between 300 and 150 mb, with Test 1 values being smaller by roughly 0.25 m/s.

Figure 10 portrays statistics for the various types of superobs as a function of pressure level. Comparing Figs. 6a and 10a shows that the number of valid superobs (“all superobs”) is still dominated by simple superobs but with obvious

increases at lower and upper levels in the two peaks. Using prisms leads to a decrease in the number of one- and two-outlier superobs and in the number of bad superobs, but a large increase in the number of isolated observations. In fact between 750 and 350 mb, the number of isolated observations exceeds the number of valid superobs. Note that the number of two-outlier superobs is too small to give valid statistics and so is not plotted for Test 2.

Innovation statistics are also shown in Figs. 6 and 10 for Tests 1 and 2, respectively. The average innovations for isolated superobs are nearly the same as those for valid superobs in Test 2, with one-outlier and bad superobs having a comparatively larger bias at both 850 mb and in the 350 to 250 mb layer (Fig. 10b). The valid superobs have a slightly lower bias at upper levels and at 600 mb in Test 2 compared to Test 1, at the expense of a slightly higher bias at mid-levels. Average innovation magnitudes (Fig. 10c) are slightly larger for isolated observations than for valid superobs at lower levels and at upper levels, with a smaller difference than was present in Test 1 (Fig. 6c). The differences in average innovation magnitude between valid superobs and both one-outlier and bad superobs are smaller in Test 2 than in Test 1.

Figure 11 shows the same statistics as a function of the number of observations per superob. Comparing the counts in Figs. 7 and 11 shows large increases in the number of valid superobs for 1 to 3 observations per superob, with decreases present at higher numbers of observations per superob. This increase is almost entirely associated with an increase in the number of simple superobs, as would be expected from the prior discussion. Over 9000 isolated observations were present in Test 2; this value is off the scale used for this figure.

The innovation statistics in Fig. 11 are little different from those in Fig. 7 for simple superobs and therefore for all valid superobs. The biases and average innovation magnitudes for one- and two-outlier superobs and for bad superobs are similar between the two tests.

The statistics for the two tests are also presented in terms of data type as a function of number of observations per superob (Fig. 12). Figure 12a shows that the change in horizontal partitioning leads to dramatic changes in some data types and much more modest changes in others. For example, the SSM/I winds in Test 1 tend to have a large number of observations per superob, with 4,442 of the 6,085 superobs using more than 15 observations per superob. However, the prism strategy used in Test 2 yields only 967 superobs with more than 15 observations per superob, but has large increases in the other categories. In contrast, the VIS winds have significant differences in only the 1, 2, and 3 observations per superob categories. The prism strategy admits more EUMETSAT single-ob superobs, with the counts roughly doubling in the 1 observation per superob category for VIS, IR, WVCLD, and WVCLR winds. While this increase occurs in part at the expense of superobs using higher numbers of observations, it also reflects the ability of the prism strategy to form superobs where the lat-lon box strategy was unable to meet the criteria to make superobs, hence the overall increase in the number of superobs (Table 2). A near doubling is also seen in the 2 observations per superob category, even for the WV winds that do not contain any EUMETSAT data. The number of IR winds with 2 observations per superob was 1,904 in Test 1 and 3,717 for Test 2.

The average speed innovation as a function of number of observations per superob is shown in Fig. 12b. While the prism strategy clearly improved the bias in most categories, it led to an increase in bias for the VIS and WVCLD winds in most categories. The bias does not appear to be an obvious function of number of observations per superob.

The average innovation magnitudes generally decrease slightly in Test 2 compared to Test 1, although IR and WVCLD winds have values that increase slightly in some categories (Fig. 12c). In addition, the decrease in the average magnitude of the speed innovations as a function of the number of observations per superob is also a function of data type. The average

innovation magnitudes for SSM/I windspeeds and for VIS winds are only a weak function of the number of observations per superob. IR winds have average innovation magnitudes that are larger for small numbers of observations per superob, but decrease to values similar to the VIS values at larger number of observations per superob. The various types of water vapor winds have even larger values for small numbers of observations per superob but have counts that are too small at large numbers of observations per superob to draw a conclusion about their variation.

Figure 13 portrays the counts and innovation statistics as a function of latitude. Comparing Figs. 13a and 8a shows that roughly the same pattern is present for both Tests 1 and 2, but with higher counts for Test 2. It is interesting to note that the peak SSM/I counts in the two hemispheres are more symmetrical in Test 2, compared to the much greater Southern Hemisphere peak in Test 1. The counts do not appear to tail off with latitude any faster in Test 2 than Test 1, indicating that varying the number of averaging volumes in a latitude band (Test 2) does not produce a dramatic difference in the number of superobs per latitude band compared to using a constant number of averaging volumes per latitude band (Test 1).

The average innovations in Fig. 13b are similar to those in Fig. 8b, but with more points plotted as a result of the greater counts in Test2. The most striking difference is the large negative bias for WVCLD winds in the subtropics. This was not apparent in Fig. 8b because these latitude bands had small counts in Test 1 and so were not plotted. Likewise, the average innovation magnitudes in Fig. 13c are quite similar to those in Fig. 8c, except for the large innovation magnitudes for WVCLD and WVCLR winds seen in the subtropics in Fig. 13c where the counts were too small to plot in Fig. 8c.

To summarize, the comparison of results between Test 1 (overlapping 2E latitude-longitude boxes) and Test 2 (non-overlapping 2E prisms) shows that Test 2 had more superobs but with slightly worse innovation statistics. The prism

strategy yields approximately a 22% increase in the number of SSM/I windspeed superobs and a 40% increase in the number of feature-track wind superobs (all channels) while using approximately 15% more observations. However, these increases are at the expense of increases of up to 0.1 m/s in the average speed innovation and the average magnitude of the speed innovation for most data types. This degradation in the statistics is associated primarily with an increase in the number of superobs with 1-3 observation per superob and, for WVCLD and WVCLR, with an increase in the number of mid-latitude superobs with larger innovations. The increase in bias and innovation magnitude is deemed small enough to make the increase in number of superobs associated with the prism strategy worthwhile. The remaining tests are therefore performed with the prism version of the code.

c) Alternate direction-based criterion (Test 2 vs. Test 3)

In Tests 1 and 2, a constraint was imposed on both u and v to limit the variation among the observations to 5 m/s. However, when the windspeed is large, a 5 m/s variation in one component can translate into a relatively small variation in wind direction. This comparison examines an alternate strategy (Test 3) in which superobs are formed from observations that have u or v components that vary by more than 5 m/s but have directions that agree within 20E. Since this test was performed using the prism version of the code, its results are compared with those from Test 2, which also used the prism version of the code.

Table 3 compares the overall statistics from Tests 2 and 3. Overall, using the alternate direction-based criterion led to an increase in the number of observations of 2.1%. Since the direction constraint is not applicable to SSM/I data, this increase was entirely in the feature-track wind data. Furthermore, this criterion acts to increase the number of high-speed superobs, most of which occur aloft (Fig. 14). An increase of 0.3% was seen for VIS superobs, which occur only at lower levels. An increase of 2.4% was seen for IR superobs, which occur

at both upper and lower levels. However, increases of 5.3% and 5.7% were seen for WV and WVCLD superobs, which occur only at upper levels. Average innovations and average innovation magnitudes were essentially unchanged, both overall (Table 3) and as a function of pressure level (not shown).

The results from this comparison show that the alternate direction-based criterion increases the number of superobs aloft without a significant change in innovation statistics. This criterion is therefore included in all further tests.

d) No time averaging (Test 3 vs. Test 4)

Time averaging was employed for feature-track winds in Tests 1-3. However, time averaging can yield superobs that are offset from the analysis time. A better strategy might be to form individual superobs for each available time and then selecting the superob nearest the analysis time. This test examines the effect of removing the time averaging without performing any superob selection.

The results for this comparison are summarized in Table 4. No changes were seen in the SSM/I windspeed superobs, which already used a time constraint, and in the WV10 and WV11 data, which are produced less frequently then other feature-track winds. The number of WV superobs, which are also produced only by UW, increased by only 6%. In contrast, the number of WVCLR superobs, which are produced only by EUMETSAT, increased by 81%. Other data types had inter-mediate increases–the number of IR superobs increased by 21%, WVCLD superobs increased by 40%, and VIS superobs increased by 53%. Changes in average innovation and average innovation magnitude were again 0.1 m/s or less.

Figure 15 shows the superob count for this comparison as a function of the number of observations per superob. The largest increases resulting from constraining time in forming superobs occurred in the one observation per superob category, which is allowed only for EUMETSAT data. Changes in

categories of three observations per superob or greater were relatively small. Changes in average innovation and average innovation magnitude as a function of number of observations per superob were small (not shown.)

To summarize, imposing time constraints leads to increases in superob counts, especially for one-observation EUMETSAT superobs, with little change in innovation statistics. Therefore, this methodology is used in remaining tests.

e) Duplicate checking (Test 4 vs. Test 5)

In the course of testing the superob code, it was found that duplicate observations were present in the dataset. Duplicates were primarily a problem for UW observations, where the same observation was typically present three times. This comparison examines the effect of checking for and rejecting these duplicates.

Figure 16 portrays the observation counts as a function of pressure level. It shows that duplicates were significant only for IR and WV observations. A total of 51,263 (16,504) IR (WV) observations were present before duplicate checking, and 46,901 (13,256) were present after duplicate checking, a reduction of 9% (20%).

Table 5 summarizes the superob statistics and shows that the decrease in observations leads to a much smaller decrease in superobs–2.0% for IR superobs and 4.5% for WV superobs–with little change in innovation statistics. The superob counts as a function of pressure level are shown in Fig. 17, which shows that only small changes are present at individual pressure levels.

Examining the superob counts as a function of the number of observations per superob shows an obvious decrease in counts for 3, 6, and 9 observations per superob, with an increase for two observations per superob (Fig. 18a). The number of isolated observations (not shown) also increased from 12,146 to 12,466 for IR winds (and from 2,519 to 2,743 for WV winds) as the observation triples that were formerly counted as three-ob superobs were reduced to

isolated observations. Average innovations decreased slightly in most categories for WV superobs with little change for IR superobs (Fig. 18b), while average innovation magnitudes decreased slightly for IR superobs with little change for WV superobs (Fig. 18c).

Since duplicate checking is correcting an error in the data, it obviously is something that should be performed and so is included in all further tests.

f) Kinetic energy adjustment (Test 5 vs. Test 6)

The next comparison examines the effect of the kinetic energy adjustment described above. This adjustment has virtually no effect on the overall statistics (not shown), because the adjustment has a significant value at only a few points. The difference between the average speed and the magnih1e.8(pc.8(s)-3.5(e (erag

Prism quartering is able to use more observations to make more superobs. The number of wind observations used in the 2002042912 dataset increased from 129,796 to 132,655 (2.2%), while the number of superobs increased from 37,232 to 38,109 (2.4%). Table 6 shows that the greatest increase occurred for WV winds–an increase of 240 superobs or 8.8%. Prism quartering has a greater effect for the higher-density satellite winds provided by UW, AFWA, and NESDIS, and little effect for the lower-density EUMETSAT and JMA winds, as shown by no change in superob counts for WVCLR winds (which are produced only by EUMETSAT).

Figure 19a shows that prism quartering increases the superob counts most for low-level VIS winds, and upper-level IR and WV winds. The increase in counts is accompanied by little change in innovation statistics (Figs. 19b,c). The largest changes in innovation statistics are seen for VIS winds at 650 mb, a level at which few VIS winds are available. Prism quartering yields worse statistics at this level, perhaps as it produces more superobs that are affected by thin cirrus.

The increase in superob count occurs not in one-observation superobs, which are allowed only for EUMETSAT winds (that are unaffected by prism quartering), but rather primarily in two- to five-observation superobs (Fig. 20). Changes in the innovation statistics as a function of the number of observations per superob (not shown) are small.

Figure 21 shows good and bad IR superobs as a function of the number of observations per superob, both with and without prism quartering. Note that isolated observations–non-EUMETSAT one-observation superobs–have been included with the bad superobs. The most obvious change is the decrease in the number of bad superobs, excluding isolated observations. The total number of bad superobs decreased from 1,786 to 1,498, all but five of which had fewer than five observations per superob and so were not accepted for quartering. At the same time, the number of isolated observations increased from 12,466 to 12,556, as a result of some quarter-prisms only containing one observation. Prism

quartering led to no discernable difference in average innovation and only a slight increase in average innovation magnitude for the good superobs.

Finally, the differences in counts between Test 5 and Test 7 are shown in Fig. 22. Prism quartering has the greatest effect in mid-to-high latitudes for SSM/I windspeeds, but primarily in the tropics and subtropics for feature-track winds. Examining the feature-track winds by type, the VIS differences have maxima at 15EN and 55EN, IR differences have maxima at 25ES and 25EN, WV differences have maxima at 25ES and 15EN, WVCLD differences peak at 5EN, and WVCLR differences are all zero. Because feature-track winds are computed from imagery from geostationary satellites, the “scene” used in tracking features covers less area in the tropics than in mid-latitudes, making the winds potentially denser in the tropics and increasing the likelihood that bad superobs have five or more observations and so qualify for quartering. The SSM/I windspeeds are computed from polar-orbiter data whose resolution has no such dependence on latitude. Therefore, prism quartering has a greater effect in mid-latitudes where the surface windspeeds are expected to be more variable. The WVCLR superobs are from EUMETSAT and are primarily one- or two-observation superobs; they therefore do not qualify for prism quartering, hence the zero differences.

Prism quartering appears to be an effective means of making better use of the data in prisms with significant speed or directional shear. Most of the observations in prisms that fail to meet the superob criteria, but that contain five or more observations, will meet those criteria after the prism is quartered.

h) No two-outlier checking (Test 7 vs. Test 8)

Checking for two outliers in the various permutations takes quite a bit of logic in the superob code for relatively little benefit. For example, there were only 435 superobs formed in Test 5 (without prism quartering) after rejecting two outliers, and only 447 in Test 7 (with prism quartering). This test was performed to

determine whether prism quartering could take the place of the two-outlier check. It used the prism version of the code that is otherwise the same as that used in Test 7.

The overall statistics for this comparison are shown in Table 7. Using prism quartering in place of the two-outlier checking yielded small increases in the number of superobs with no change in the innovation statistics, with the exception of a 0.1 m/s increase in the average innovation magnitude for SSM/I windspeeds.

Figure 23 shows the superob counts as a function of pressure level. The counts show slight increases in the low-level VIS winds and the upper-level IR and WV winds, with changes smaller than those seen when prism quartering was added (Fig. 19a). Only small changes were present in the innovation statistics (not shown).

Even so, the details of the impact of two-outlier checking vary with data type. Figure 24 shows the statistics as a function of number of observations per superob for WV winds. Omitting the two-outlier checking gave noticeable increases in the number of rejected isolated observations and in the number of superobs with two and three observations (Fig. 24a). The two-outlier superobs were sufficiently biased that prism quartering gave a lower bias for good superobs (Fig. 24b) as well as a smaller average innovation magnitude (Fig. 24c) for 5 to 8 observations per superob. On the other hand, omitting two-outlier checking for IR winds led to small increases in bias for good superobs for 6, 7, and 12 observations per superob, but again smaller average magnitudes for 5 to 9 observations per superob (Fig. 25). Finally, omitting the two-outlier checking for SSM/I windspeeds led to an increase in bias for three-observation superobs, and a larger average innovation magnitude for the 1- and 2-observation superobs that were not used and for the 3- and 4-observation superobs that were used (Fig. 26). This is noteworthy because these increases occurred for the categories where superobs were most numerous.

In short, omitting two-outlier checking improved the WV statistics, gave mixed results for IR superobs, and degraded the SSM/I statistics. Prism quartering seems to be about as effective as two-outlier checking for feature-track winds, but performs more poorly for SSM/I windspeeds. Consequently, the two-outlier checks are retained for the last two tests.

i) Increased speed criterion (Test 7 vs. Test 9)

This section presents the results from the tests of using 7 m/s rather than 5 m/s for the speed criterion in forming superobs from feature-track winds, making the speed criterion consistent with the criteria for u and v.

The statistics for this comparison are summarized in Table 8. Increasing the speed threshold to 7 m/s increases the number of feature-track winds overall, but actually slightly decreases the number of VIS superobs. Apparently, prism quartering was invoked fewer times for the VIS winds, as more prisms pass the criteria without quartering. Except for the WV10 average speed innovation (which have only 70 superobs with the new criterion), the overall innovation statistics are not affected by changing the speed criterion.

Figure 27 shows the counts as a function of pressure level for the various data types. The increased speed criterion has its greatest effect at upper levels, where it leads to slight increases in the counts for IR, WV, and WVCLD winds and only small changes in the innovation statistics (not shown). The increased counts are most obvious for two observations per superob (Fig. 28a). The difference in average innovation is small, with the increased speed criterion giving a value nearer zero in some case but not in others (Fig. 28b). However, the small differences in average innovation magnitude are decreases for superobs with five or fewer observations, the categories with the largest counts (Fig. 28c).

Because increasing the speed criterion leads to small improvements in the innovation statistics and because this change corrects an inconsistency in the criteria, this change is recommended for future use.

j) Low-accuracy SSM/I observations (Test 9 vs. Test 10)

The final test in this series examines the inclusion of lower accuracy SSM/I observations. Since SSM/I precipitable water observations use the same superobbing strategy as SSM/I windspeed observations, they will also be discussed in this section.

1) Windspeed

Most of the tests described in this paper did not affect the SSM/I data; the tests that did are summarized in Table 9. Most of the SSM/I windspeeds are high accuracy ocean points. (Possible ice points were previously determined to be of poorer quality and so are rejected prior to superobbing.) Including the low accuracy points increases the observation count from 73,045 to 88,262, an increase of 21%. However, the lower accuracy points also increased the average innovation magnitudes for the observations by 0.1 m/s.

Examining the statistics for the accepted superobs, there is no difference in overall innovation statistics between Tests 1, 2, and 7, although the counts increase by a total of 25% (Table 9). However, adding the low accuracy observations leads to a further increase in superob count of 19%, a decrease in average innovation, but an increase in average innovation magnitude. Except for Test 1, the isolated superobs (those with fewer than three observations per superob) have a count of approximately 2,400 and average innovation magnitudes that are 0.3 m/s larger than that for the accepted superobs from the same test. Including low-accuracy superobs also leads to a larger bias–0.2 m/s vs. 0.0 m/s. These statistics also show that prism quartering reduced the number of rejected superobs to almost zero, even with low-accuracy observations included.

Figure 29 portrays the superob statistics as a function of number of observations per superob. The comparison here is between Test 9, which is identical to Test 7 for the SSM/I data, and Test 10, which includes the low-

accuracy observations. The Test 10 counts are higher than the Test 9 counts in all categories, but also have a larger bias for low numbers of observations per superob, where the counts are highest. The Test 10 average innovation magnitudes are also greater than or equal to those for Test 9 in all categories. Furthermore, the low-accuracy observations are concentrated in the tropics. Figure 30 shows that the largest differences in superob count occur between 20EN and 20ES, with average innovations close to zero (compared to negative values seen without the low-accuracy points), and with differences in average innovation magnitude greater in mid-latitudes than in the tropics.

Low-accuracy observations occur at possible rain points, where the technique used to determine the windspeed is less accurate. In addition, the innovations are larger for larger windspeeds and larger for low-accuracy points with the same windspeed (not shown). Adding the low-accuracy points therefore would be expected to have a greater effect in mid-latitudes where surface windspeeds are generally greater, as can be seen in the average innovation magnitudes in Fig. 30c. It is therefore recommended that low-accuracy windspeed observations not be used.

2) Precipitable water

The same statistics are now examined for precipitable water (PW). It should be noted that the accuracy flag is intended to apply primarily to windspeed observations. This examination is performed to see if the PW values at low-accuracy points have different characteristics from those at high-accuracy points. Including the low-accuracy observations increases the observation counts from 62,198 to 74,686, an increase of 20% (Table 10). Note that these counts are much lower than those for SSM/I windspeeds. Rejecting all observations with an innovation greater than 10 g/m^2 eliminates more observations than the three-tiered threshold used for windspeed. Including the

low-accuracy observations also increases the average innovation from 0.2 to 0.4 g/m^2 and the average magnitude of the innovation from 1.7 to 1.9 g/m^2.

Superobbing the PW observations decreases the average magnitude of the innovation without affecting the average innovation. In addition, Table 10 shows that significant increases in superob count occur as the prism scheme and prism quartering are introduced. In fact, with prism quartering the PW superob count exceeds the windspeed superob count by 102 superobs, compared to 954 fewer for prisms without quartering. The larger impact of quartering seen for PW compared to windspeed indicates that the more PW prisms have a variability greater than 5 g/m^2, either a reflection that the threshold is set too low or the field has more inherent variability. While quartering has no effect on the innovation statistics for windspeed, it leads to an increase in average innovation magnitude for PW–1.3 g/m^2 vs. 1.5 g/m^2. Like windspeed, the isolated superobs (as well as the rejected superobs) have greater biases and greater average innovation magnitudes than the accepted superobs, supporting the decision not to use these superobs.

Comparing superobs with and without low-accuracy observations shows that the number of one to five observation superobs increases to a greater extent than superobs with six or more observations (Fig. 31), in contrast to the nearly equal increases seen for SSM/I windspeeds (Fig. 29). Using the low-accuracy PW observations also leads to a more dramatic increase in bias than seen for windspeeds. The PW bias also occurs in all categories. However, the average magnitude of the innovation actually decreases for five or fewer observations per superob when low-accuracy observations are used, although it does increase at higher numbers of observations per superob.

As for windspeed, the increase in the number of superobs associated with using low-accuracy data occurs primarily in the tropics (Fig. 32a). However, unlike windspeed, the already large bias in the tropics is made even larger by using the low-accuracy points (Fig. 32b). The largest differences in average

innovation magnitude also occur in the tropics, where innovation magnitudes are greatest (Fig. 32c). It is possible that the innovation statistics are worse for the low-accuracy points more as a result of the background field being less accurate in the tropics than as a result of the observations being of poorer quality. However, these observations are placed in the lower accuracy category because they occur at possible rain locations. Since a global model likely does not portray rain at exactly the observed locations, especially in the tropics, it is recommended that the low-accuracy PW observations not be used to form superobs.

5. Recommendations

The configuration of the superob code used in Test 9 is proposed for implementation in NAVDAS. To be specific, this configuration uses prisms with the alternate direction criterion, no time averaging, duplicate checking, prism quartering, two-outlier checking, and the increased speed criterion. A comparison with the results from Test 1, the superob code currently used, is discussed in this section to summarize the preceding discussion.

The proposed superob code (Test 9) generated 7,625 SSM/I windspeed superobs and 30,862 feature-track wind superobs, compared to 6,085 SSM/I windspeed superobs and 15,833 feature-track wind superobs using the old superob code (Test 1). The vertical distribution of these superobs is shown in Fig. 33a. While increases occurred at all levels, the increases are most dramatic at low and upper levels, with only small increases seen at mid-levels where the counts were already small. Furthermore, the increases are greatest for EUMETSAT data, because of the removal of time averaging. WVCLR winds are generated only by EUMETSAT and have counts that nearly triple, while WV winds are generated only by UW and have counts that fall short of doubling.

A comparison of average innovations and average innovation magnitudes is shown in Figs. 33b,c. The largest differences in average innovation occur where the counts are lowest. Focusing instead on levels where

the counts are higher, the new superob code has biases that are fairly similar to those in the old superob code–worse in some cases and better in others. The same can be said for the average innovation magnitudes, although these are larger more often for the new superob code. A comparison of the overall statistics for Test 1 (Table 1) and for Test 9 (Table 8) shows this same ambiguity.

The statistics as a function of number of observations per superob are given in Fig. 34 for this comparison. Aside from the large decrease in SSM/I windspeed superobs with more than fifteen observations, the most dramatic differences occur at three or fewer observations per superob. In this range, the average innovation magnitudes are smaller for the new superob code, with the biases showing mixed results.

Innovation statistics, however, can only suggest which changes might perform better; the final proof will be in a side-by-side comparison of NAVDAS runs. Therefore, it is recommended that such an experiment be performed to compare the current configuration with the Test 9 configuration.

Finally, several other possible tests have suggested themselves in the course of running the current set of tests. These are listed below, in no particular order.

- Test the superob code for QuikScat and MODIS winds.
- Allow the top and bottom of the 50 mb vertical averaging interval to be determined from the data rather than forcing the 50 mb layers to be centered on exact multiples of 50 mb.
- Select a subset of superobs rather than using all of them–for example, the superob nearest the analysis time within a particular data type. Or, perhaps IR superobs at lower levels should be used in place of VIS superobs, since the IR superobs seem to have a lower bias and a lower average innovation magnitude. Or, perhaps superobs nearer the satellite subpoint should be used in place of those far from the subpoint where data from different satellites overlap.

- Mix channels/satellites in the same superob. The current strategy seeks to average only like observations. However, this results in multiple superobs for the same volume. A test should be performed to see whether keeping different types of data separate is worthwhile.
- Stagger averaging volumes horizontally. The MultiVariate Optimum Interpolation (MVOI) analysis system currently operational at FNMOC superobs UW observations in averaging volumes that are staggered with respect to those used for NESDIS observations. That option is available in NAVDAS using the prism code.
- Implement a vertical shear check. It is suspected that the positive bias in IR and VIS winds at low levels is associated with cirrus contamination. These low-level winds could be rejected where they are similar to upper-level winds in the same volume.
- Reject observations at pressure levels where they are available in small numbers. For example, the IR superobs at 100 and 150 mb and the WV superobs at 150 mb have a significant positive bias, likely a result of height assignment errors. VIS superobs above 700 mb have a small bias, but a large innovation magnitude, larger than IR superobs at those levels.
- Set the observation error in NAVDAS to be a function of the number of observations per superob or a function of the data type. The statistics presented in this paper show that the average innovation magnitude is a function of the number of observations per superob at least for some data types. Furthermore, the average innovation magnitudes are not the same for the various types of water vapor winds, for IR, and for VIS winds, suggesting that they should not be assigned the same observation error.
- Include other feature-track wind single-observation superobs. The UW/AFWA and NESDIS single-observation superobs do not appear to any worse than the EUMETSAT single-observation superobs. They could be included to extend the coverage of the satellite superobs, especially if the

observation error is made a function of number of observations per superob.

APPENDIX

Switches in the New Superob Code

This section describes how the various tests using the new version of the satellite wind superob code were performed. Test 1, which used the old version of the code, is not discussed here.

Table A1 lists key parameters from the prism version of subroutine satwind_qc, the main subroutine used in the satellite wind superob code, along with the choices used in the tests described in this paper. These parameters are set in parameter statements at the beginning of the subroutine.

Two of the tests using the prism version of the code were performed using a modified version of the code rather than by changing the setting for one of the parameters. Omitting the alternate direction criterion and using time averaging were both accomplished by commenting out appropriate sections of the code.

The remaining test, using the low-accuracy SSM/I observations was accomplished by modifying subroutine rej_obs to set ichk_ob to zero for both SSM/I windspeed and precipitable water observations. This can be done by uncommenting both of the bold lines in Figure A1, which is a fragment from rej_obs. Subroutine rej_obs is called by satwind_qc.

Table A1: Selected parameters used in satwind_qc.

Parameter	**Value(s) used in tests**	**Description**
sup_grid	2.0E	Superob (prism) grid size
l_i_stagger	true	Stagger prisms in longitude (centered on odd longitudes at the equator if true)
l_j_stagger	false	Stagger prisms in latitude (centered on even latitudes if false)
l_correct_uv	false (true in Test 6)	Use kinetic energy adjustment if true
l_dupcheck	true (false in Tests 2-4)	Perform duplicate checking if true
k_try_end	2 (1 in Tests 2-6)	Perform prism quartering if set to 2, not if set to 1
spd_thresh	7.0 m/s (5.0 m/s in Tests 2-8)	Speed criterion used in forming feature-track wind superobs
l_do_outlier	true	Perform checking for 1 or 2 outliers if true
l_do_2_outliers	true (false in Test 8)	Perform checking for 2 outliers if true
l_pc	true (set to false on UNIX machines)	Set path names for PC if true
l_use_mid_VIS	true	Use mid-level VIS winds if true
l_use_mid_IR	true	Use mid-level IR winds if true
l_use_low_WV	true	Use mid-level WV winds if true

```
c
c Examine only obs with positive ichk_ob values
c ---------------------------------------------
        if(ichk_ob(ii).gt.0) then
c
c         If SSMI ocean surface wind accuracy is 1 (2-5 m/s),
c         disallow windspeed--just count
c         (Set ichk_ob(ii) = 0 to use these obs)
c         ---------------------------------------------------
          if(insty_ob(ii).eq.i_ssmi_sp.and.
     $       ichk_ob(ii).ne.0) then
c
c            ichk_ob(ii) = 0
            knt_ssmi_sp1 = knt_ssmi_sp1 + 1
c
c         Disallow SSMI PW's with wind accuracies of 1 or 2
c         (Set ichk_ob(ii) = 0 to use these obs)
c         -------------------------------------------------
          elseif(insty_ob(ii).eq.i_ssmi_pw.and.
     $           ichk_ob(ii).ne.0) then
c
c            ichk_ob(ii) = 0
            knt_ssmi_pw1 = knt_ssmi_pw1 + 1
```

Figure A1: Portion of code from subroutine rej_obs.

Table 1: Statistics by data type for Test 1. Statistics include count, average speed innovation (AVG) and average magnitude of the speed innovation (MAG), both of which are given in m/s.

Data Type	Observations		Test 1 Superobs	
	Count	AVG MAG	Count	AVG MAG
SSM/I windspeed (FNMOC)	73,045	0.0 1.5	6,085	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	22,146	0.6 1.7	2,353	0.4 1.7
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	51,263	0.1 2.3	8,155	0.0 2.1
Water-vapor(WV) wind vectors (UW)	16,504	0.2 3.0	1,864	0.2 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	16,827	-0.5 3.2	2,249	-0.4 2.9
WVCLR (clear) wind vectors (EUMETSAT)	3,355	-0.3 3.6	1,065	-0.4 3.4
WV10 (ch. 10) wind vectors (UW)	314	0.9 2.5	53	0.7 2.0
WV11 (ch. 11) wind vectors (UW)	536	1.3 2.9	94	1.2 2.8
Total	183,990		21,918	

Table 2: Same as Table 1, except for superobs from Test 1 (old superob code) and Test 2 (prism superob code).

Data Type	Test 1 Superobs		Test 2 Superobs	
	Count	AVG MAG	Count	AVG MAG
SSM/I windspeed (FNMOC)	6,085	-0.1 1.3	7,458	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	2,353	0.4 1.7	3,762	0.5 1.7
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	8,155	0.0 2.1	10,346	0.1 2.2
Water-vapor(WV) wind vectors (UW)	1,864	0.2 2.7	2,563	0.3 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	2,249	-0.4 2.9	3,717	-0.5 3.0
WVCLR (clear) wind vectors (EUMETSAT)	1,065	-0.4 3.4	1,658	-0.4 3.6
WV10 (ch. 10) wind vectors (UW)	53	0.7 2.0	66	1.4 2.5
WV11 (ch. 11) wind vectors (UW)	94	1.2 2.8	128	1.2 2.6
Total	21,918		29,698	

Table 3: Same as Table 1, except for superobs from Tests 2 and 3, which differ only in the use of the alternate direction criterion in Test 3.

Data Type	**Test 2 Superobs**		**Test 3 Superobs**	
	Count	**AVG MAG**	**Count**	**AVG MAG**
SSM/I windspeed (FNMOC)	7,458	-0.1 1.3	7,458	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	3,762	0.5 1.7	3,775	0.5 1.7
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	10,346	0.1 2.2	10,591	0.1 2.2
Water-vapor(WV) wind vectors (UW)	2,563	0.3 2.7	2,698	0.3 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	3,717	-0.5 3.0	3,929	-0.5 3.0
WVCLR (clear) wind vectors (EUMETSAT)	1,658	-0.4 3.6	1,672	-0.4 3.5
WV10 (ch. 10) wind vectors (UW)	66	1.4 2.5	67	1.3 2.6
WV11 (ch. 11) wind vectors (UW)	128	1.2 2.6	130	1.2 2.6
Total	29,698		30,320	

Table 4: Same as Table 1, except for superobs from Tests 3 and 4, which differ only in the use of time averaging in Test 3.

Data Type	**Test 3 Superobs**		**Test 4 Superobs**	
	Count	**AVG MAG**	**Count**	**AVG MAG**
SSM/I windspeed (FNMOC)	7,458	-0.1 1.3	7,458	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	3,775	0.5 1.7	5,774	0.5 1.6
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	10,591	0.1 2.2	12,800	0.1 2.2
Water-vapor(WV) wind vectors (UW)	2,698	0.3 2.7	2,859	0.4 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	3,929	-0.5 3.0	5,504	-0.4 3.1
WVCLR (clear) wind vectors (EUMETSAT)	1,672	-0.4 3.5	3,024	-0.4 3.6
WV10 (ch. 10) wind vectors (UW)	67	1.3 2.6	67	1.3 2.6
WV11 (ch. 11) wind vectors (UW)	130	1.2 2.6	130	1.2 2.6
Total	30,320		37,616	

Table 5: Same as Table 1, except for superobs from Tests 4 and 5, which differ only in the use of duplicate checking in Test 5.

Data Type	Test 4 Superobs		Test 5 Superobs	
	Count	AVG MAG	Count	AVG MAG
SSM/I windspeed (FNMOC)	7,458	-0.1 1.3	7,458	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	5,774	0.5 1.6	5,774	0.5 1.6
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	12,800	0.1 2.2	12,546	0.1 2.2
Water-vapor(WV) wind vectors (UW)	2,859	0.4 2.7	2,730	0.3 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	5,504	-0.4 3.1	5,503	-0.4 3.1
WVCLR (clear) wind vectors (EUMETSAT)	3,024	-0.4 3.6	3,024	-0.4 3.6
WV10 (ch. 10) wind vectors (UW)	67	1.3 2.6	67	1.3 2.6
WV11 (ch. 11) wind vectors (UW)	130	1.2 2.6	130	1.2 2.6
Total	37,616		37,232	

Table 6: Same as Table 1, except for superobs from Tests 5 and 7, which differ only in the use of prism quartering in Test 7.

Data Type	Test 5 Superobs		Test 7 Superobs	
	Count	AVG MAG	Count	AVG MAG
SSM/I windspeed (FNMOC)	7,458	-0.1 1.3	7,625	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	5,774	0.5 1.6	5,894	0.5 1.6
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	12,546	0.1 2.2	12,774	0.1 2.2
Water-vapor(WV) wind vectors (UW)	2,730	0.3 2.7	2,970	0.3 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	5,503	-0.4 3.1	5,622	-0.4 3.1
WVCLR (clear) wind vectors (EUMETSAT)	3,024	-0.4 3.6	3,024	-0.4 3.6
WV10 (ch. 10) wind vectors (UW)	67	1.3 2.6	67	1.3 2.6
WV11 (ch. 11) wind vectors (UW)	130	1.2 2.6	133	1.2 2.6
Total	37,232		38,109	

Table 7: Same as Table 1, except for superobs from Tests 7 and 8, which differ only in the use of two-outlier checking in Test 7.

Data Type	Test 7 Superobs		Test 8 Superobs	
	Count	AVG MAG	Count	AVG MAG
SSM/I windspeed (FNMOC)	7,625	-0.1 1.3	7,780	-0.1 1.4
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	5,894	0.5 1.6	5,945	0.5 1.6
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	12,774	0.1 2.2	12,866	0.1 2.2
Water-vapor(WV) wind vectors (UW)	2,970	0.3 2.7	3,051	0.3 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	5,622	-0.4 3.1	5,664	-0.4 3.1
WVCLR (clear) wind vectors (EUMETSAT)	3,024	-0.4 3.6	3,024	-0.4 3.6
WV10 (ch. 10) wind vectors (UW)	67	1.3 2.6	67	1.3 2.6
WV11 (ch. 11) wind vectors (UW)	133	1.2 2.6	133	1.2 2.6
Total	38,109		38,530	

Table 8: Same as Table 1, except for superobs from Tests 7 and 9, which differ only in the use of the increased speed criterion in Test 9.

Data Type	Test 7 Superobs		Test 9 Superobs	
	Count	AVG MAG	Count	AVG MAG
SSM/I windspeed (FNMOC)	7,625	-0.1 1.3	7,625	-0.1 1.3
Visible (VIS) wind vectors (UW, NESDIS, EUMETSAT)	5,894	0.5 1.6	5,892	0.5 1.6
Infrared (IR) wind vectors (UW, NESDIS, EUMETSAT, JMA)	12,774	0.1 2.2	12,903	0.1 2.2
Water-vapor(WV) wind vectors (UW)	2,970	0.3 2.7	3,055	0.3 2.7
WVCLD (cloudy) wind vectors (NESDIS, EUMETSAT, JMA)	5,622	-0.4 3.1	5,767	-0.4 3.1
WVCLR (clear) wind vectors (EUMETSAT)	3,024	-0.4 3.6	3,041	-0.4 3.6
WV10 (ch. 10) wind vectors (UW)	67	1.3 2.6	70	1.4 2.6
WV11 (ch. 11) wind vectors (UW)	133	1.2 2.6	134	1.2 2.6
Total	38,109		38,487	

Table 9: Statistics for SSM/I windspeed tests. Average innovations (AVG) and averages of the innovation magnitudes (MAG) are given in m/s.

Test	**Count**	**AVG**	**MAG**
High accuracy obs	73,045	0.0	1.5
High and low accuracy obs	88,262	0.0	1.6
Accepted superobs			
Test 1–old superob code	6,085	-0.1	1.3
Test 2–prism code	7,458	-0.1	1.3
Test 7–prism with quartering	7,625	-0.1	1.3
Test 10–prism with low-accuracy	9,040	0.0	1.4
Isolated (1 or 2 obs) superobs–not accepted			
Test 1–old superob code	2,721	0.2	1.3
Test 2–prism code	2,370	0.0	1.6
Test 7–prism with quartering	2,386	0.0	1.6
Test 10–prism with low-accuracy	2,482	0.2	1.7
Rejected superobs			
Test 1–old superob code	448	0.1	1.6
Test 2–prism code	48	1.2	1.7
Test 7–prism with quartering	0	--	--
Test 10–prism with low-accuracy	4	2.3	2.3

Table 10: Statistics for SSM/I total precipitable water tests. Average innovations (AVG) and averages of the innovation magnitudes (MAG) are given in g/m^2.

Test	**Count**	**AVG**	**MAG**
High accuracy obs	62,198	0.2	1.7
High and low accuracy obs	74,686	0.4	1.9
Accepted superobs			
Test 1–old superob code	4,730	0.2	1.1
Test 2–prism code	6,504	0.2	1.3
Test 7–prism with quartering	7,727	0.2	1.5
Test 10–prism with low-accuracy	9,395	0.4	1.6
Isolated (1 or 2 obs) superobs–not accepted			
Test 1–old superob code	2,234	0.0	1.3
Test 2–prism code	2,841	0.3	1.7
Test 7–prism with quartering	3,164	0.3	1.8
Test 10–prism with low-accuracy	3,467	0.6	2.0
Rejected superobs			
Test 1–old superob code	2,092	0.2	1.5
Test 2–prism code	434	0.2	1.7
Test 7–prism with quartering	34	0.3	1.9
Test 10–prism with low-accuracy	40	0.5	1.8

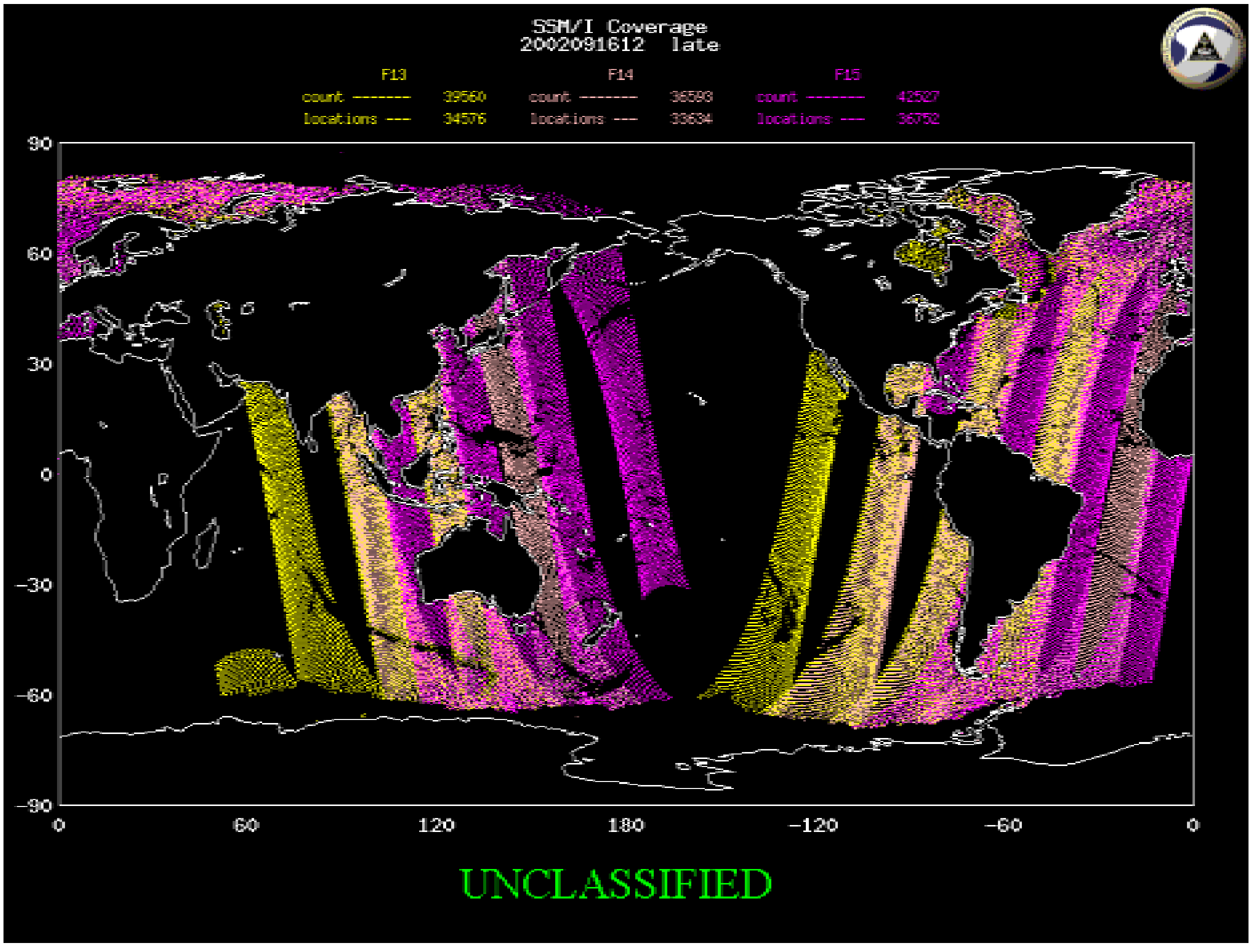


Figure 1: Data distribution within the six-hour time window centered on 1200 UTC 16 September 2002 for SSM/I windspeeds. Data from the three current DMSP satellites are color-coded as shown on the figure. (Coverage diagram courtesy of FNMOC)

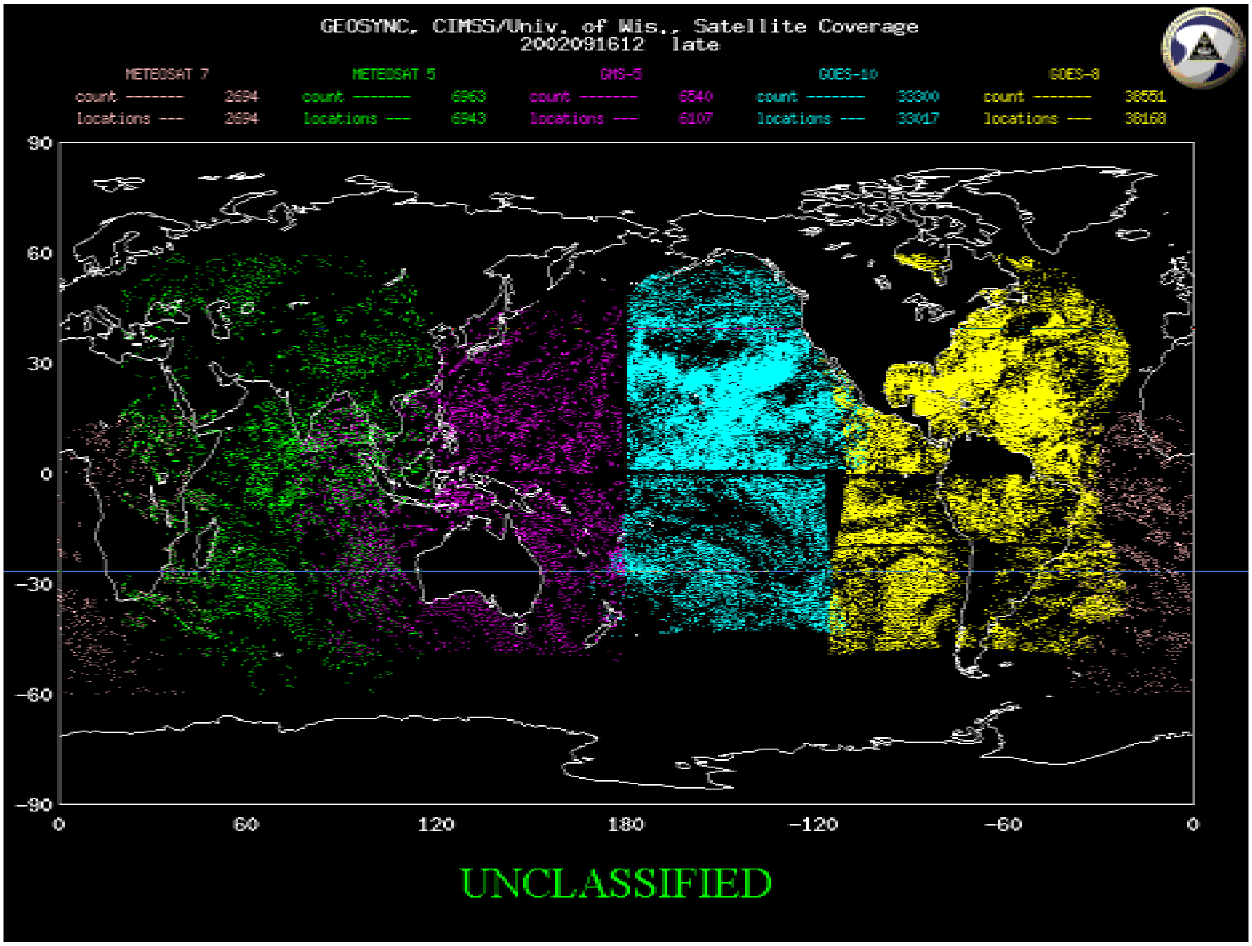


Figure 2: Data distribution within the six-hour time window centered on 1200 UTC 16 September 2002 for UW CIMSS feature-track winds. Data from the five current meteorological geostationary satellites are color-coded as shown on the figure. (Coverage diagram courtesy of FNMOC)

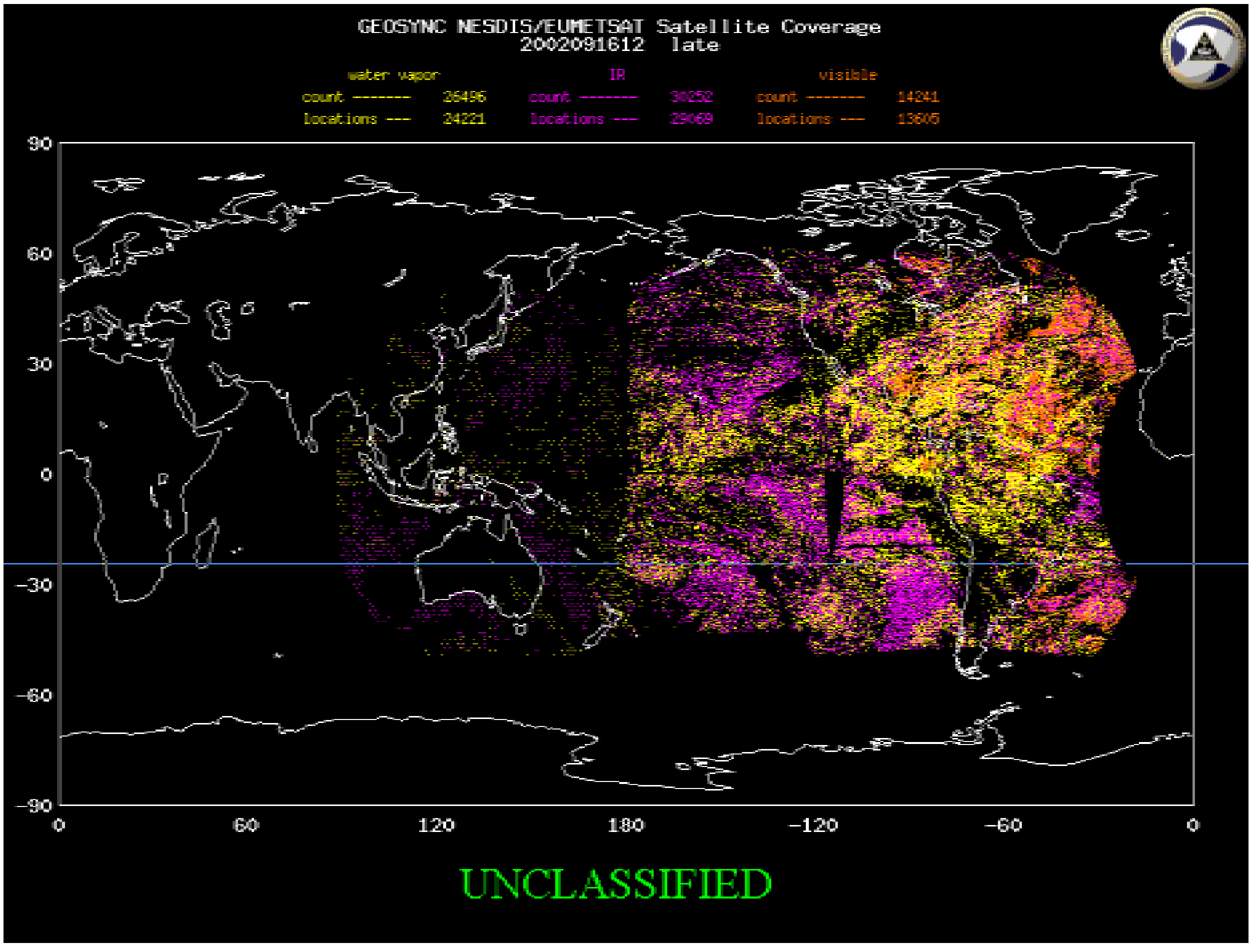


Figure 3: Data distribution within the six-hour time window centered on 1200 UTC 16 September 2002 for NESDIS and JMA feature-track winds. NESDIS winds are processed only from GOES-8 and GOES-10 and so cover the Americas, the eastern Pacific, and the western Atlantic. JMA winds are processed only from GMS-5 and so cover the western Pacific. Data from the visible, infrared, and water-vapor channels are color-coded as shown on the diagram. (Coverage diagram courtesy of FNMOC)

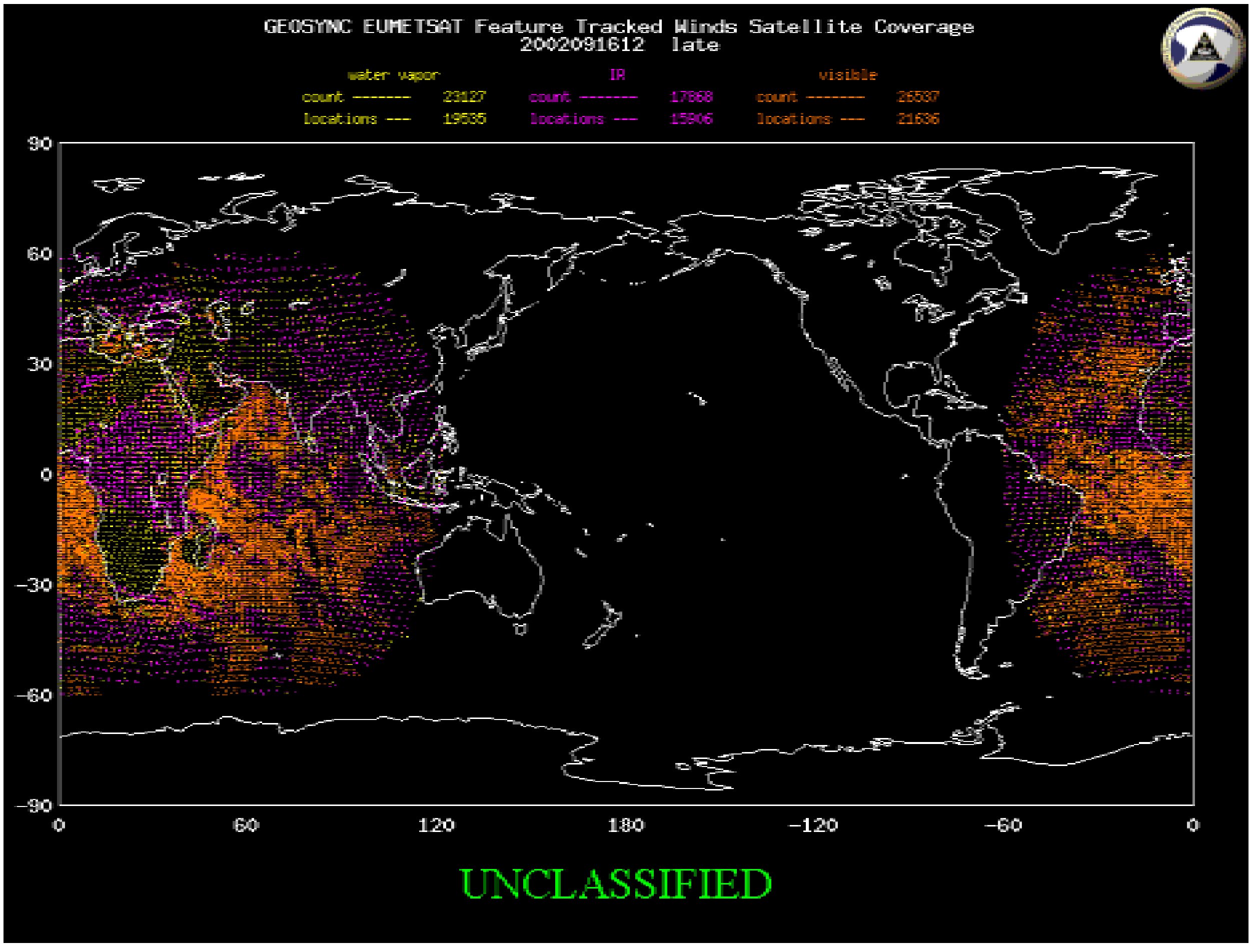


Figure 4: Data distribution within the six-hour time window centered on 1200 UTC 16 September 2002 for EUMETSAT feature-track winds. EUMETSAT winds are processed only for Meteosat-5 and Meteosat-7. Data from the visible, infrared, and water-vapor channels are color-coded as shown on the diagram. (Coverage diagram courtesy of FNMOC)

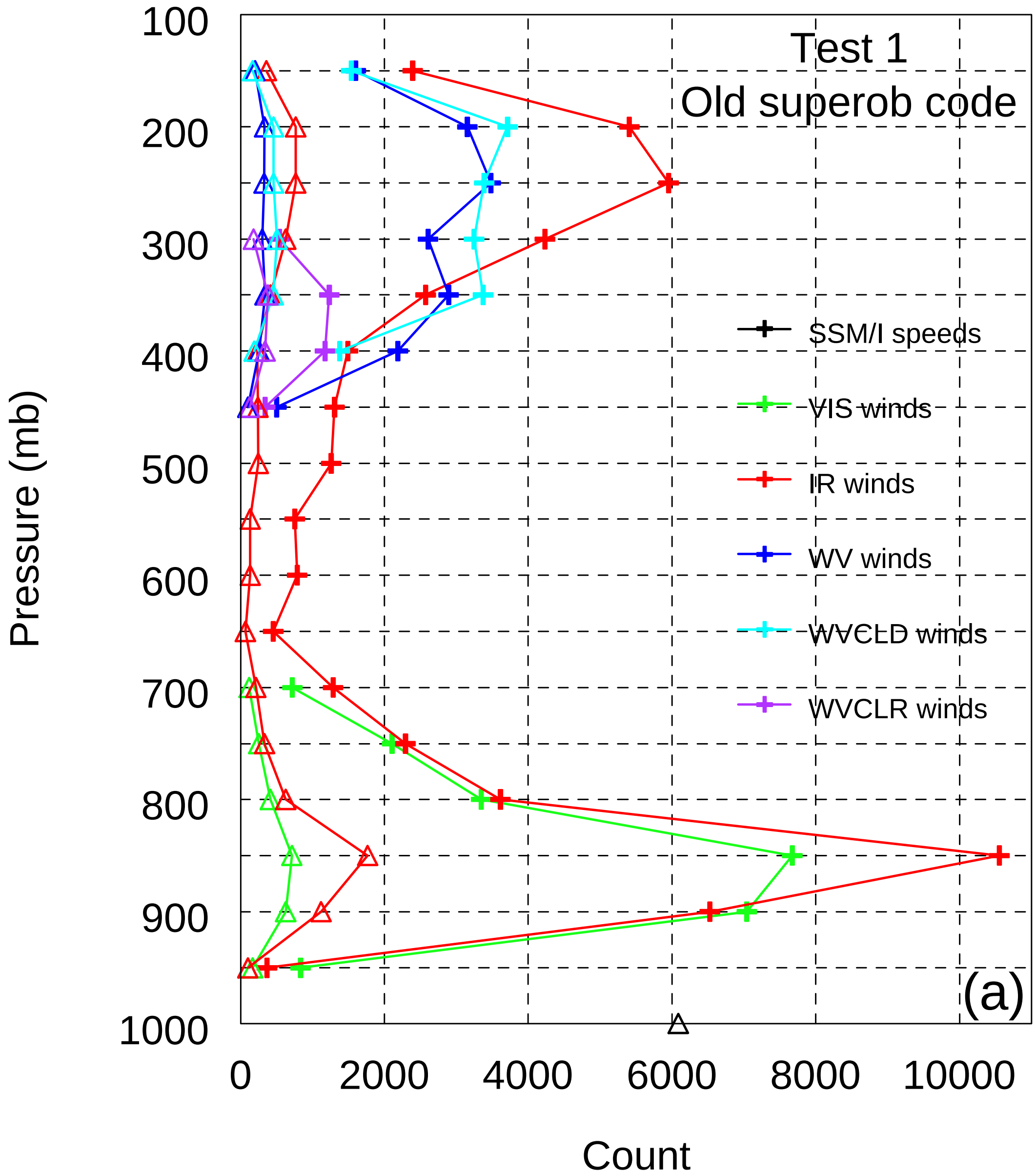


Figure 5: (a) Observation/superob count, (b) average speed innovation (m/s), and (c) average magnitude of the speed innovation (m/s) as a function of pressure level for various satellite wind data types. Observations are shown as plus signs and superobs from Test 1 as open triangles. Statistics for points with fewer than 50 superobs have been omitted.

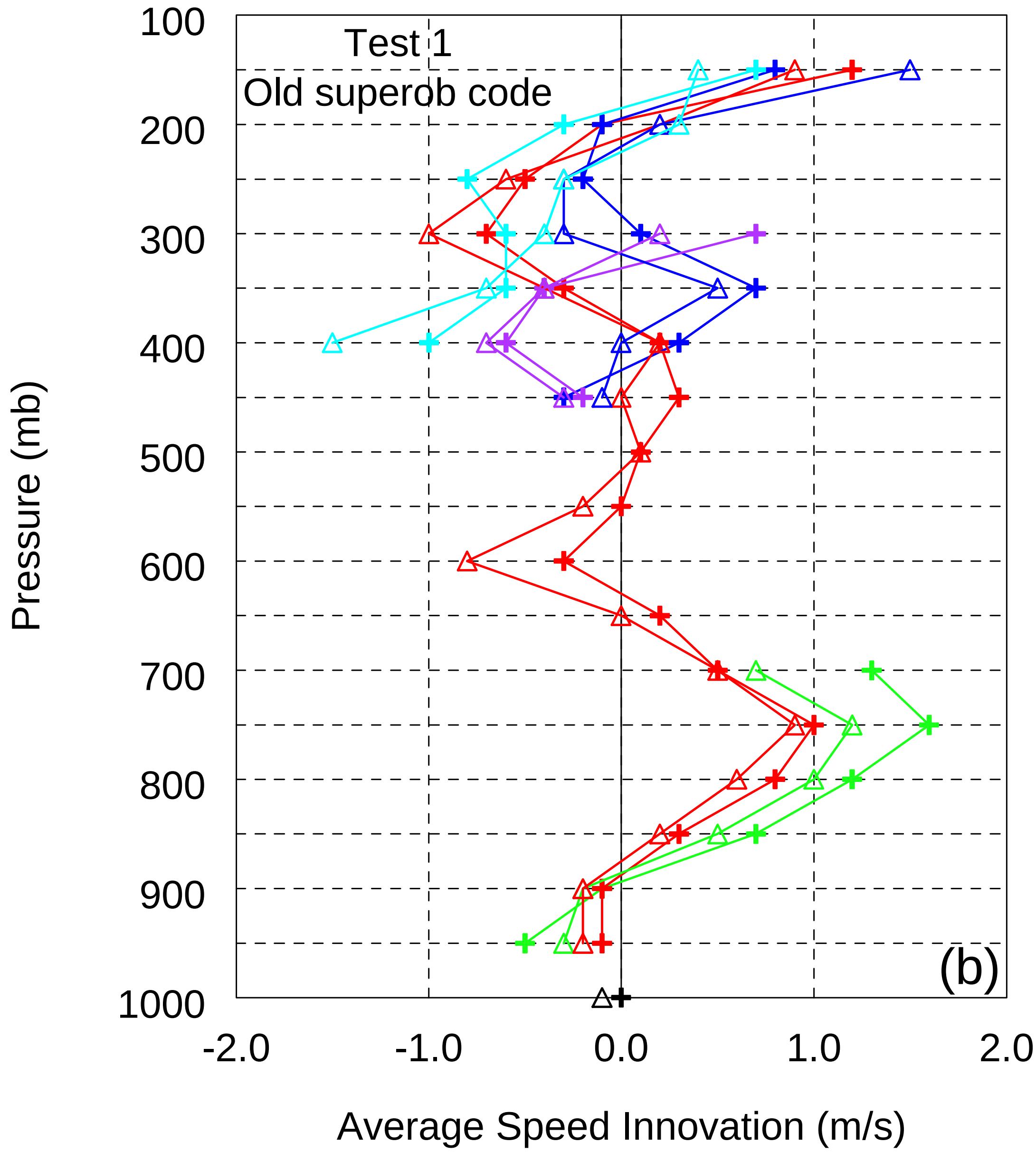


Figure 5: (continued)

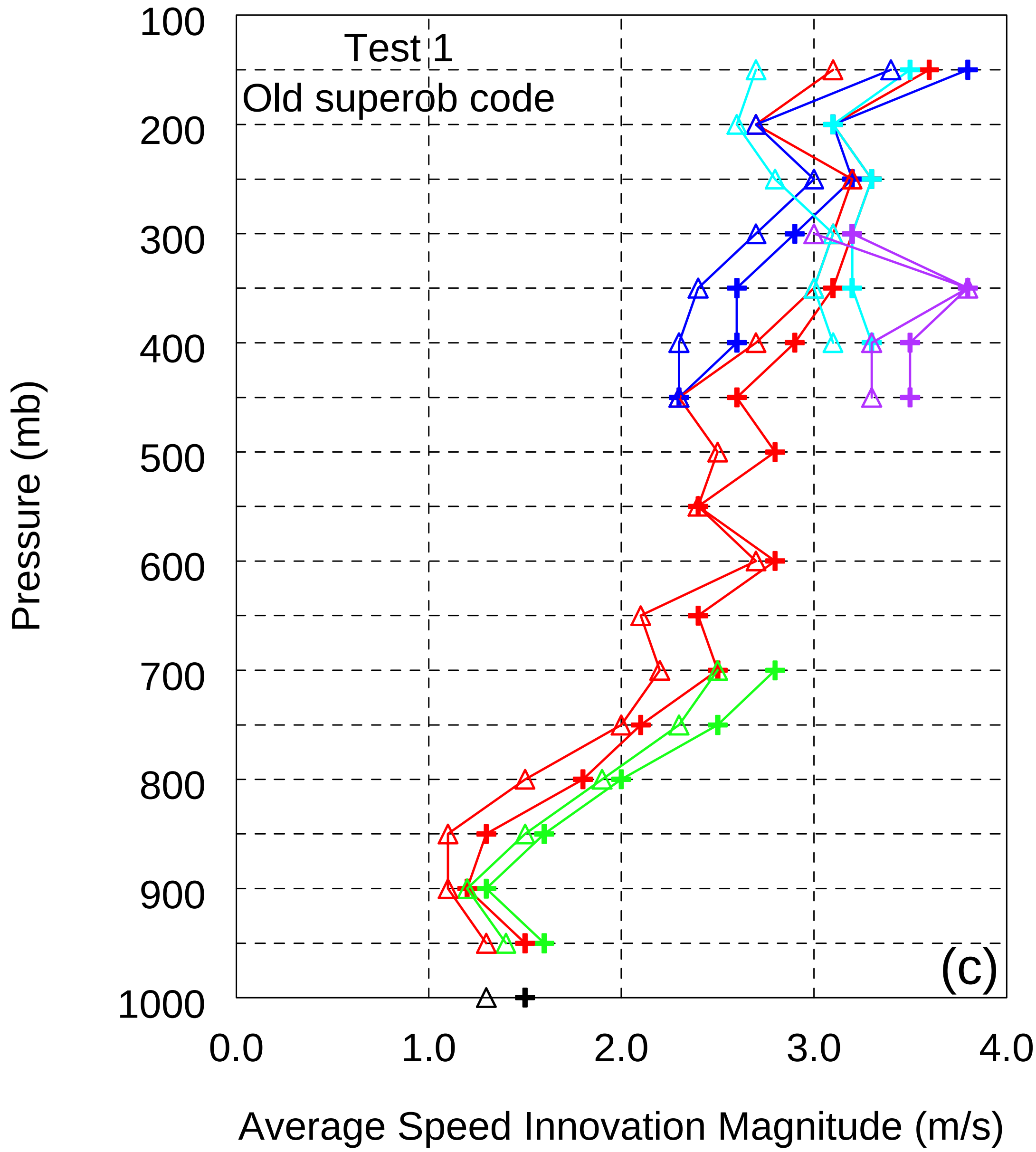


Figure 5: (continued)

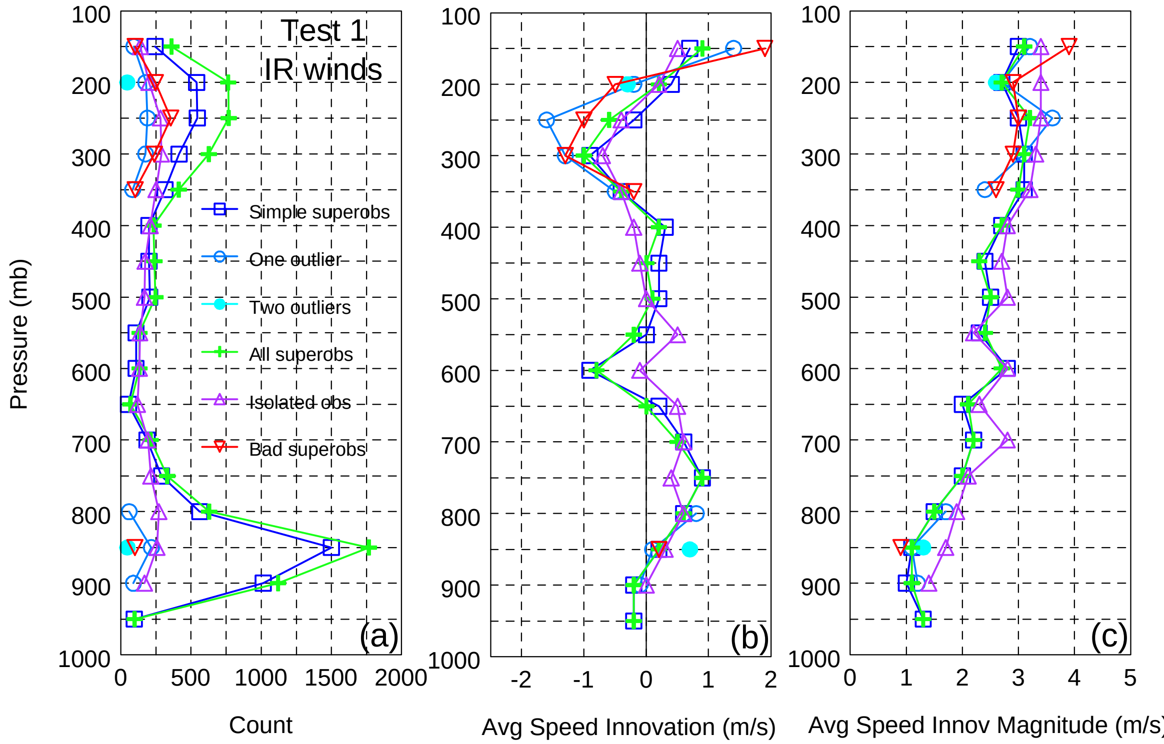


Figure 6: (a) Superob count, (b) average speed innovation (m/s), and (c) average magnitude of the speed innovation (m/s) as a function of pressure level for IR feature-track winds from Test 1. The type of superob is color-coded as indicated in the legend. Statistics for points with fewer than 45 superobs have been omitted.

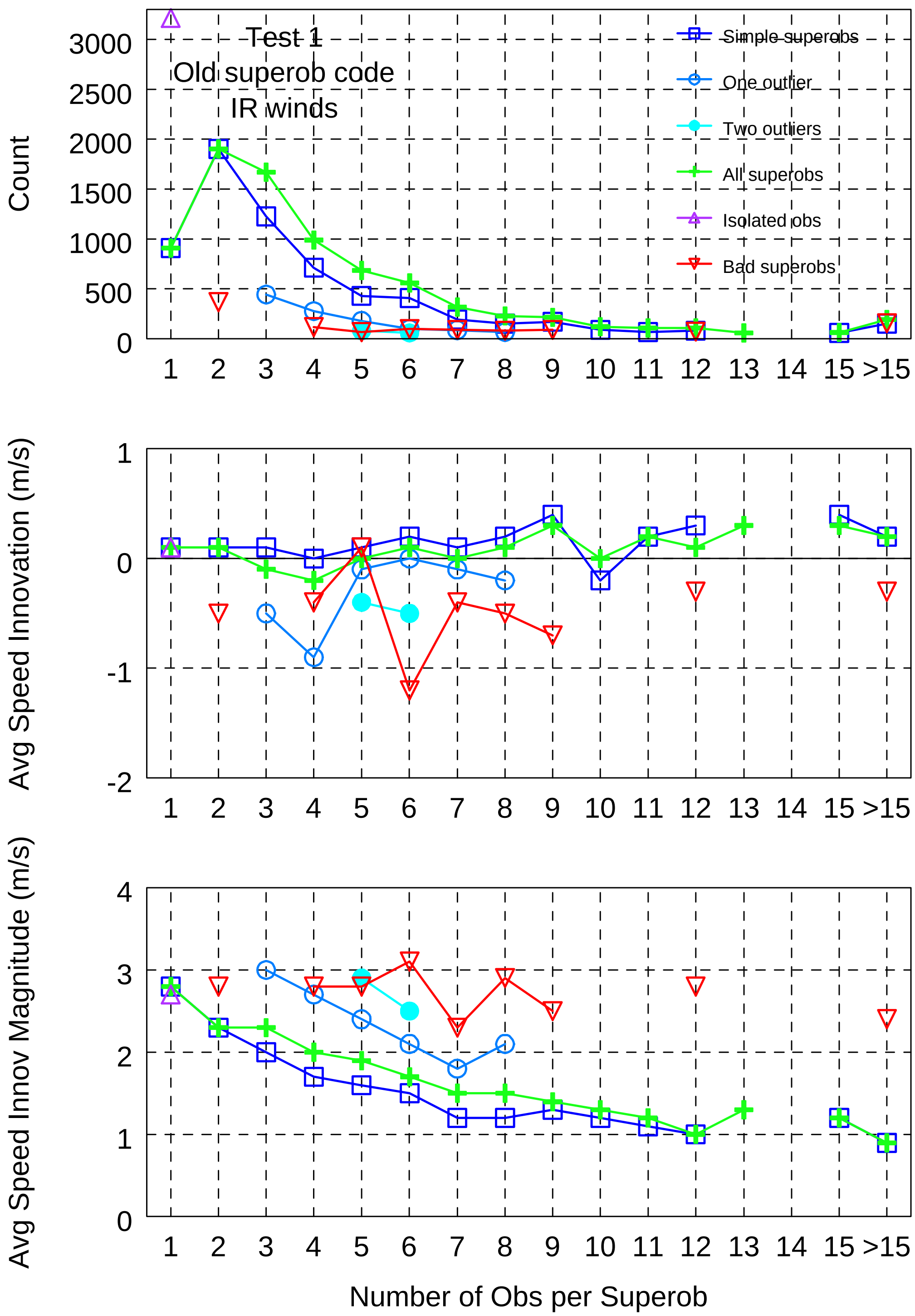


Figure 7: Superob count (top), average speed innovation (m/s) (center), and average magnitude of the speed innovation (m/s) (bottom) as a function of number of observations per superob for IR feature-track winds from Test 1.

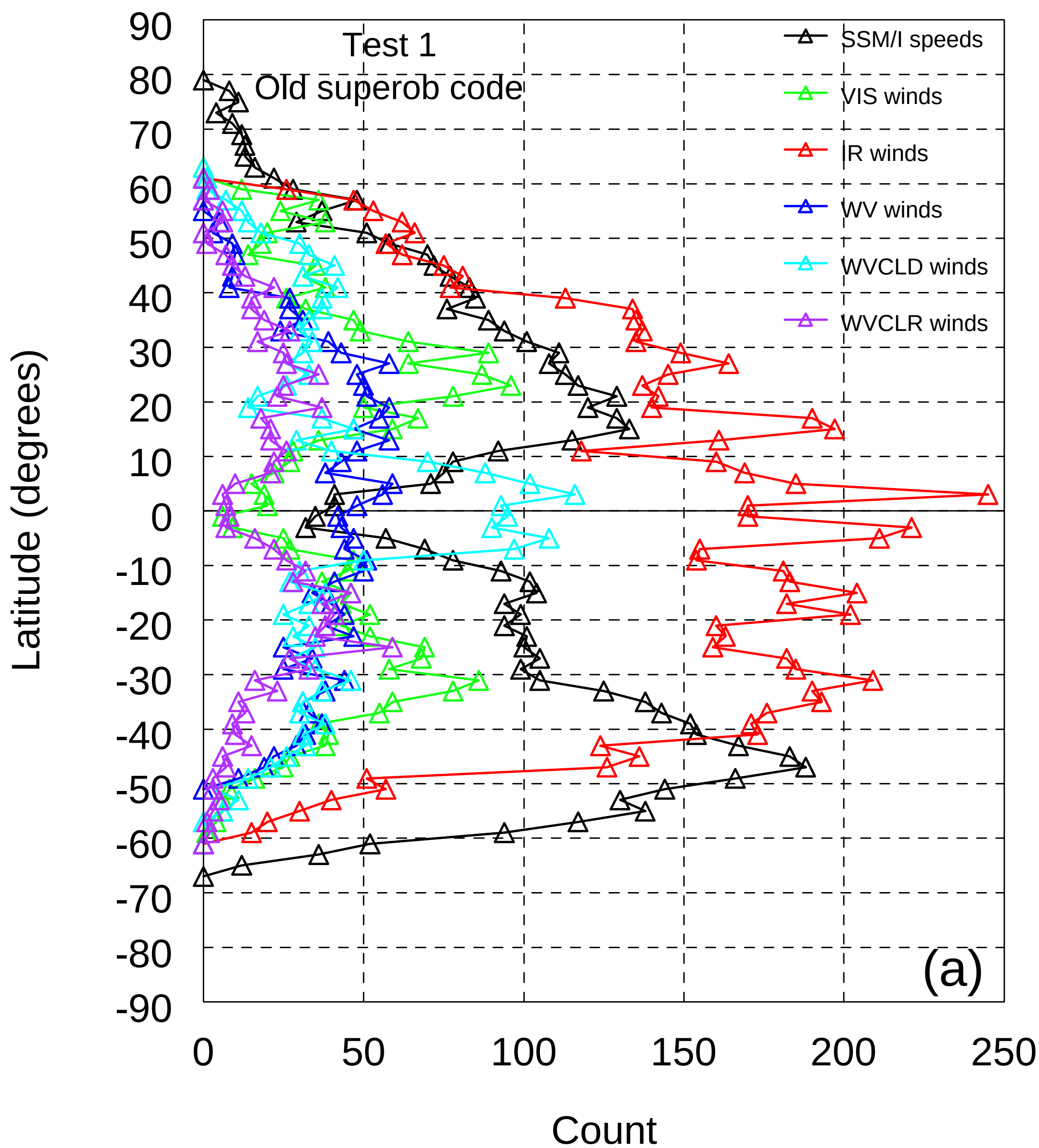


Figure 8: (a) Superob count, (b) average speed innovation (m/s), and (c) average magnitude of the speed innovation (m/s) as a function of latitude for various satellite wind data types from Test 1. Except for counts, statistics for points with fewer than 50 superobs have been omitted.

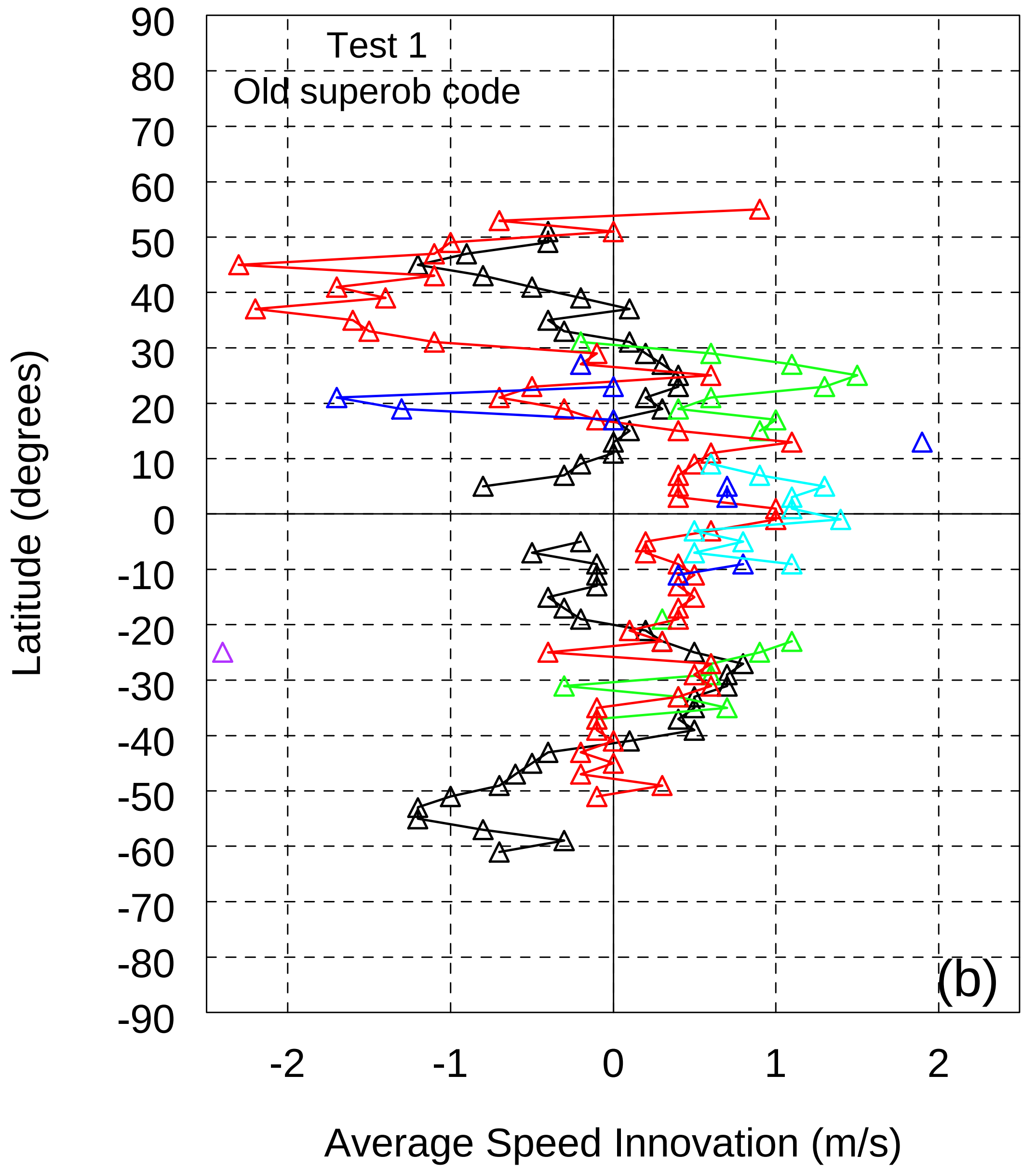


Figure 8: (continued)

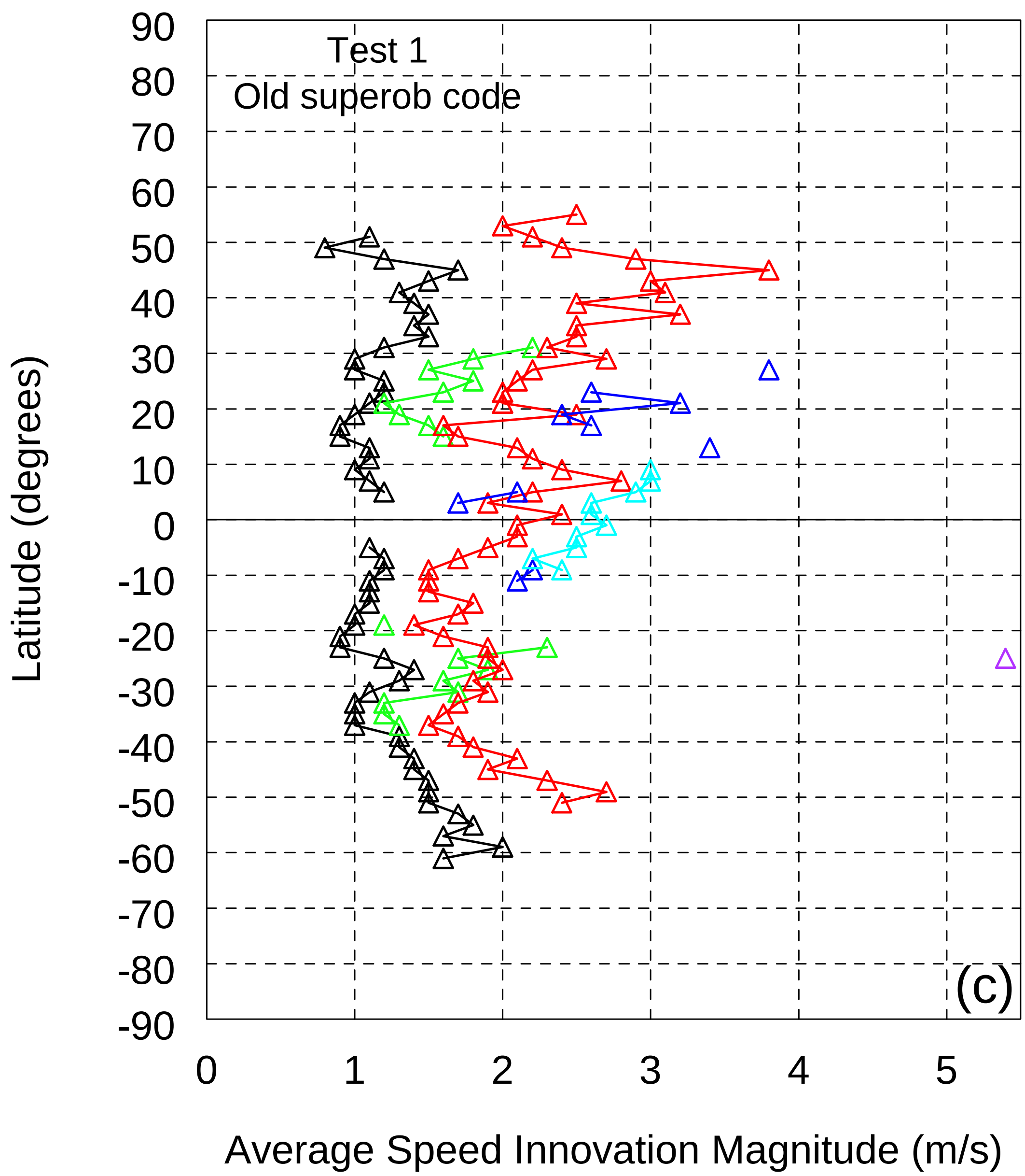


Figure 8: (continued)

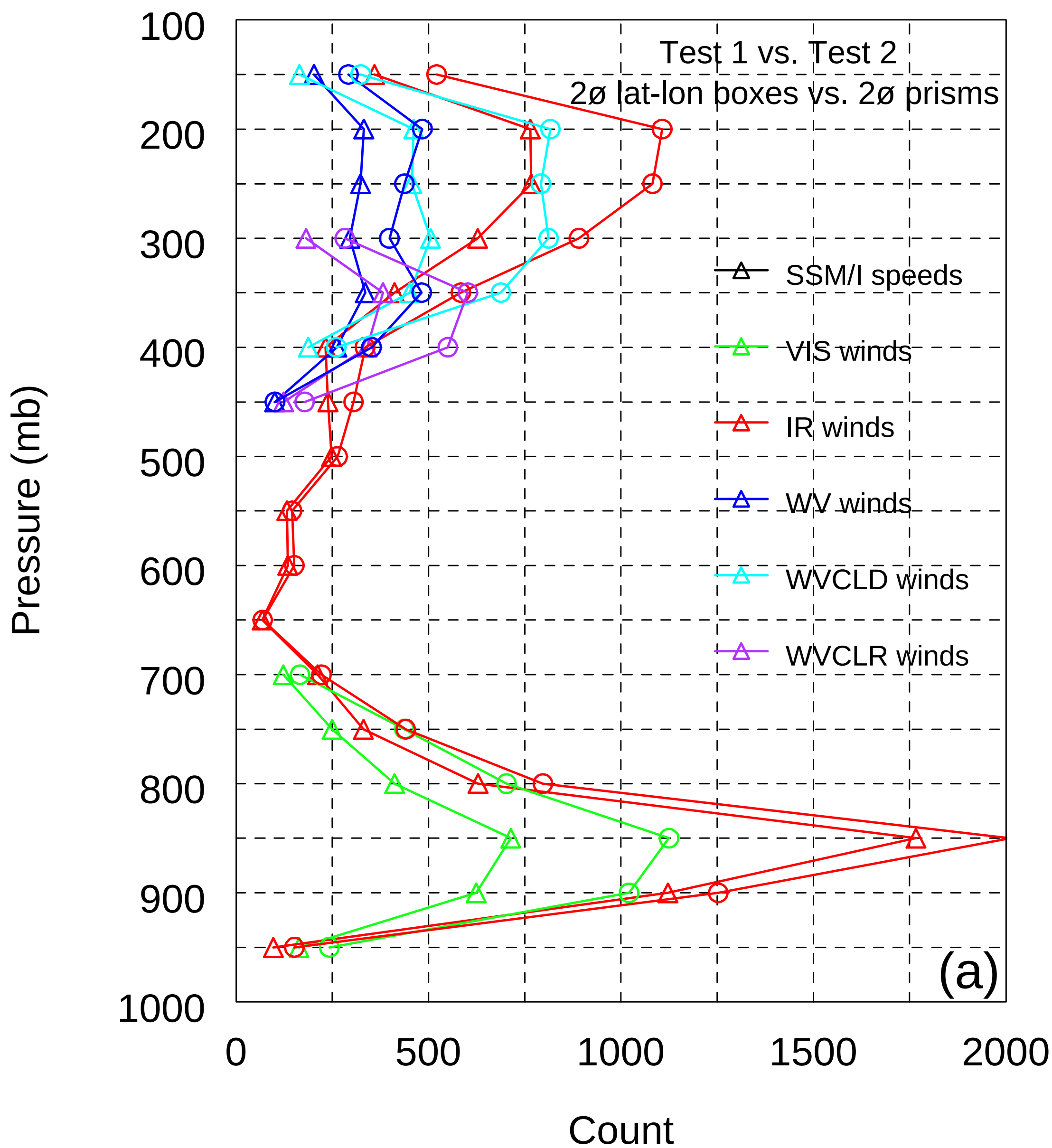


Figure 9: Same as Fig. 5 except for the comparison between Test 1 (open triangles) and Test 2 (open circles).

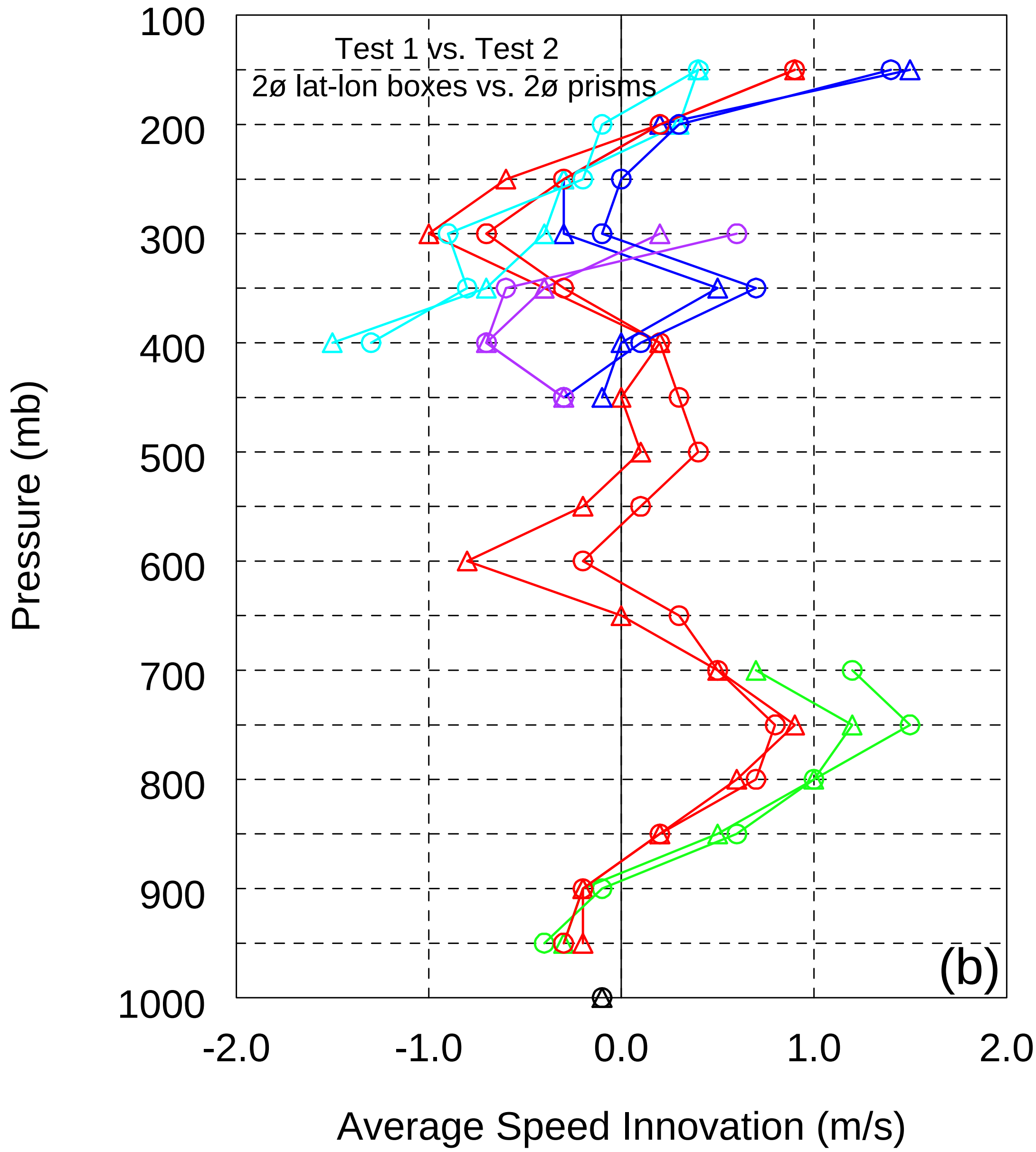


Figure 9: (continued)

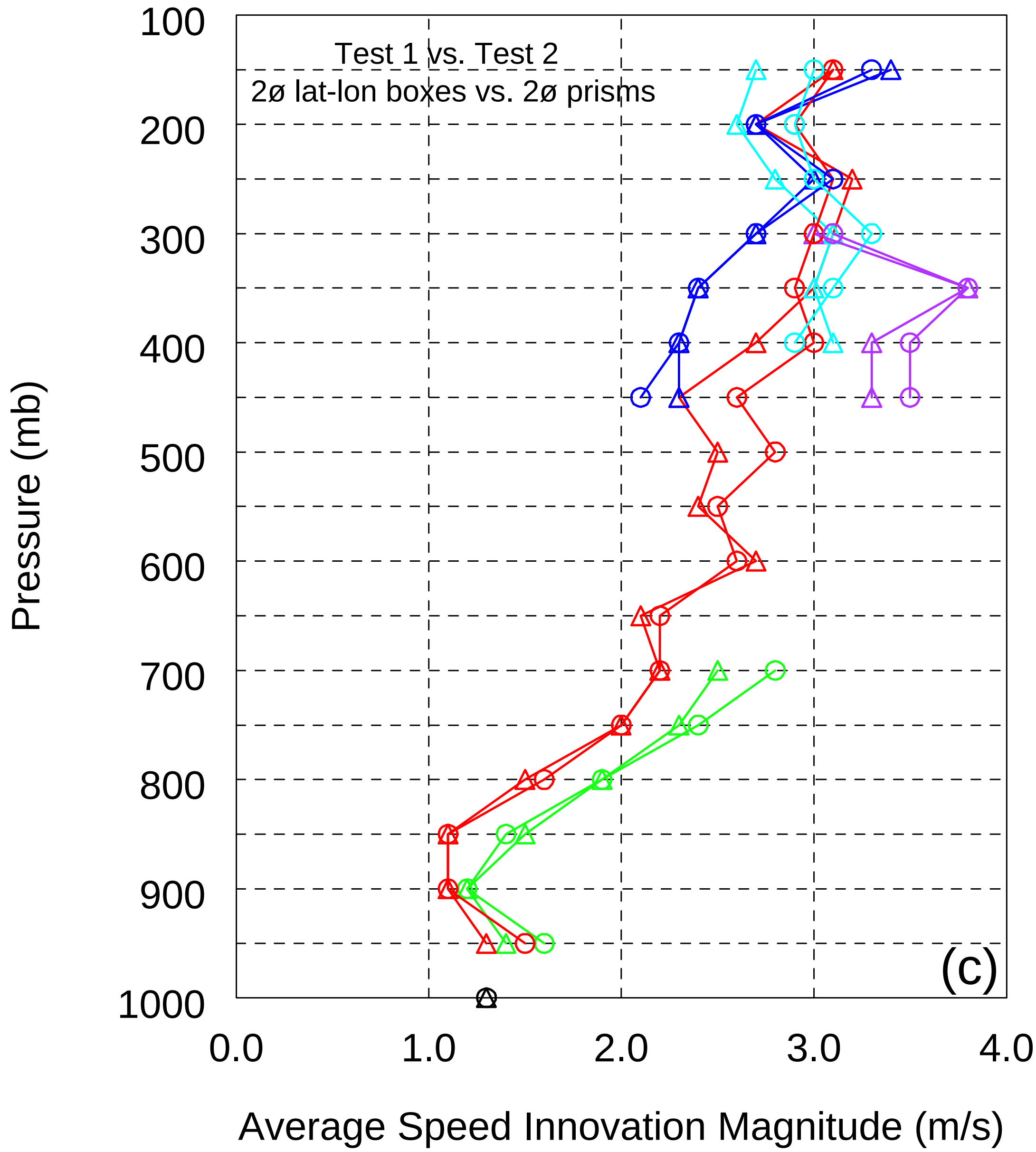


Figure 9: (continued)

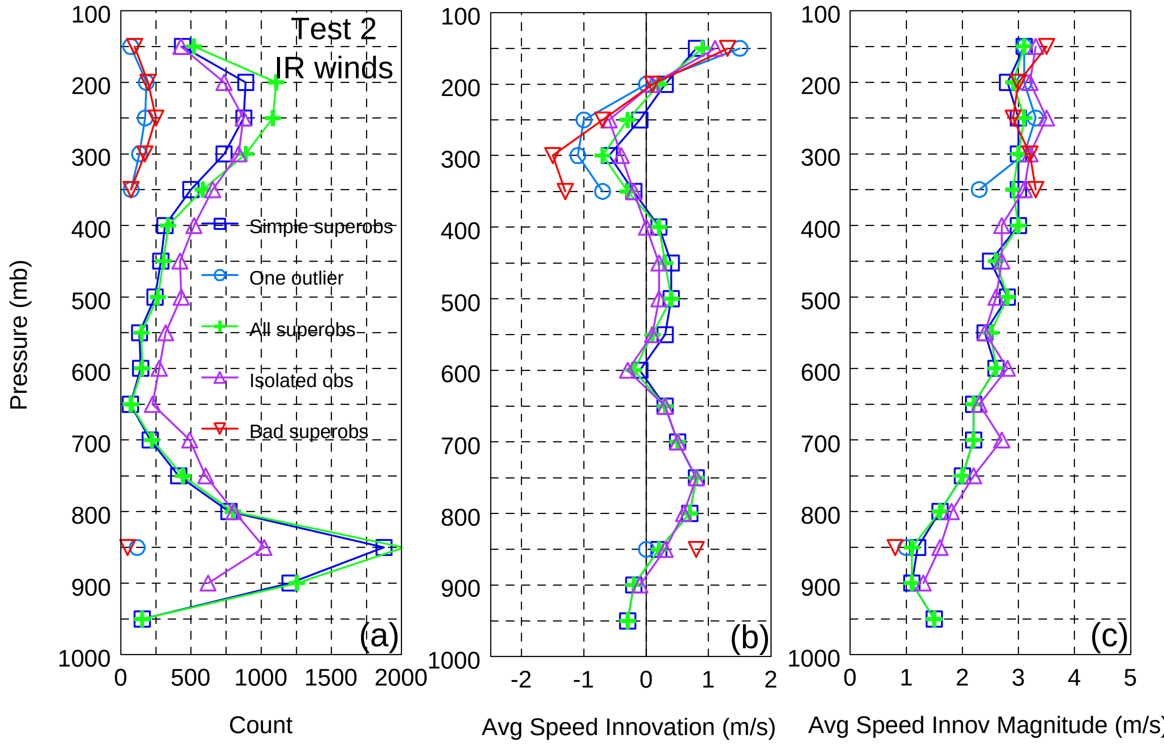


Figure 10: Same as Fig. 6 except for Test 2 (2E prisms).

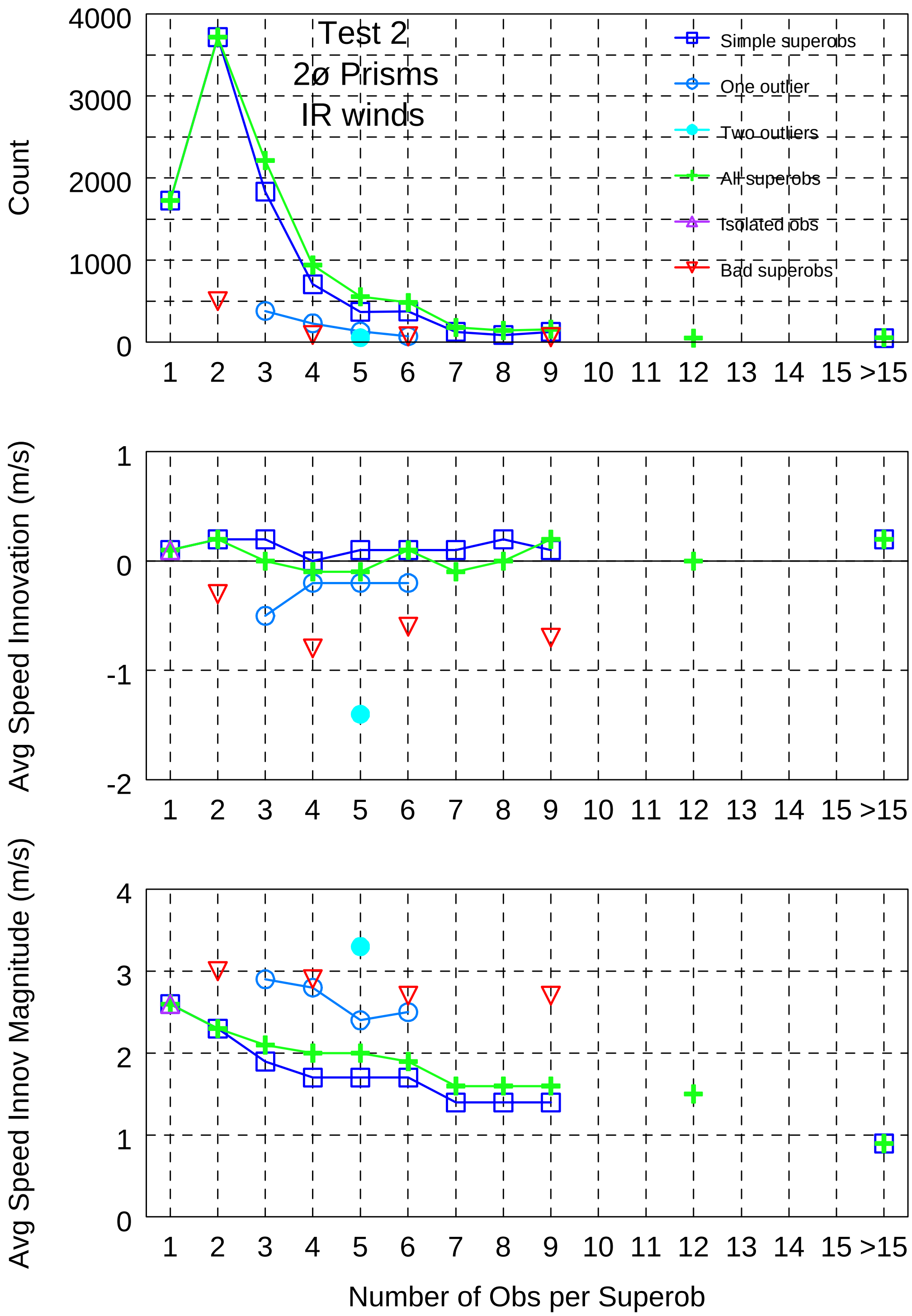


Figure 11: Same as Fig. 7 except for Test 2 (2E prisms).

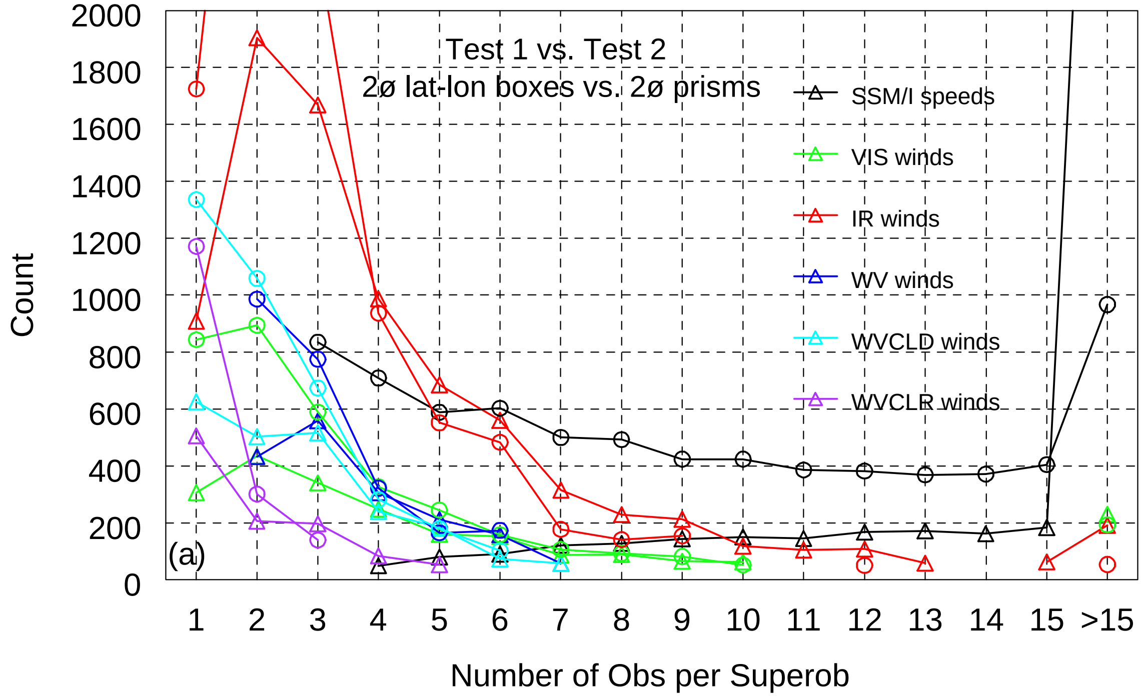


Figure 12: (a) Superob count, (b) average speed innovation (m/s), and (c) average magnitude of the speed innovation (m/s) as a function of number of observations per superob for various satellite wind data types. Superobs from Test 1 (2E latitude/longitude boxes) are shown as open triangles, and superobs from Test 2 (2E prisms) are shown as open circles. Statistics for points with fewer than 50 superobs have been omitted.

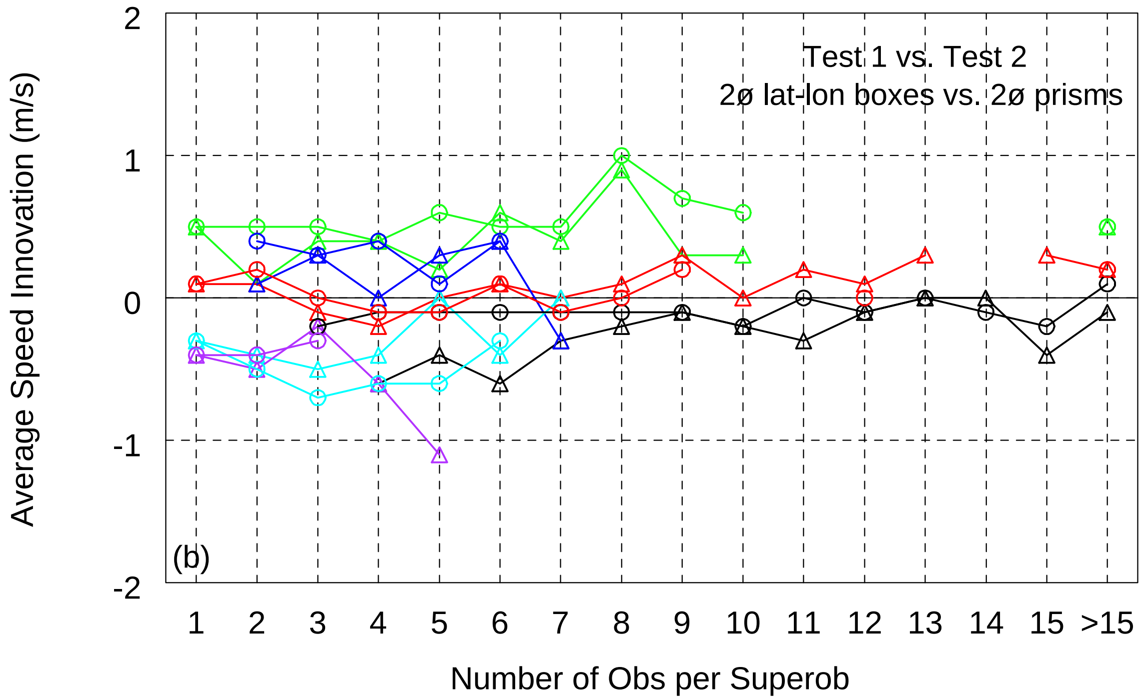


Figure 12: (continued)

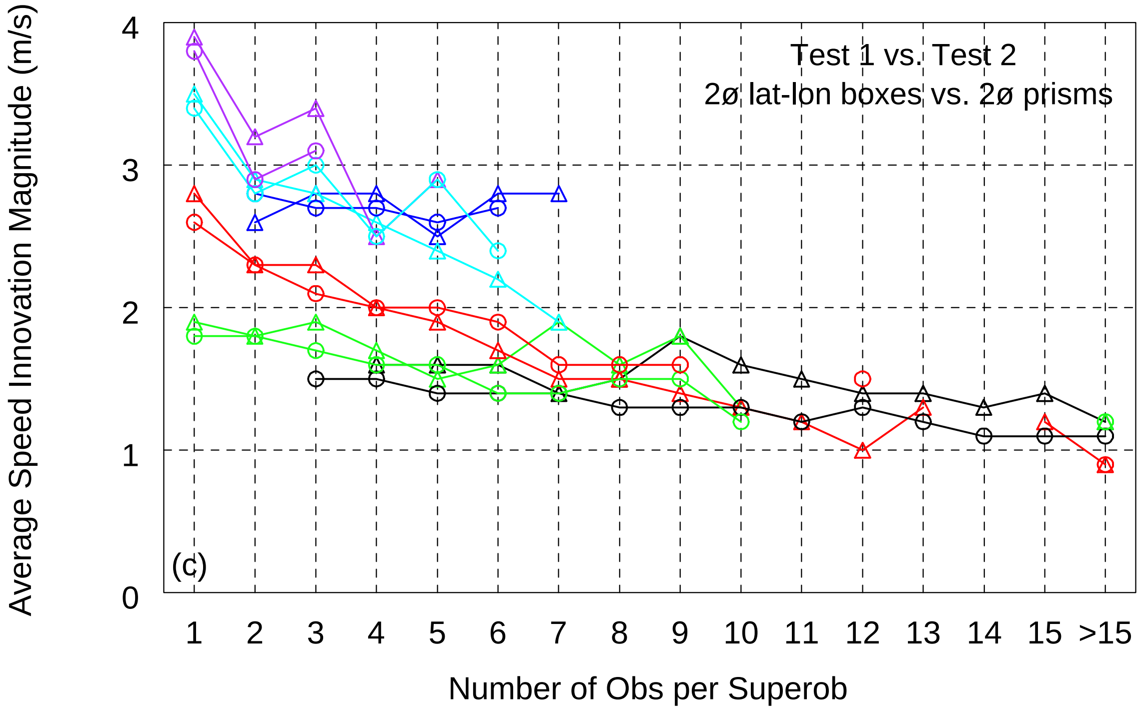
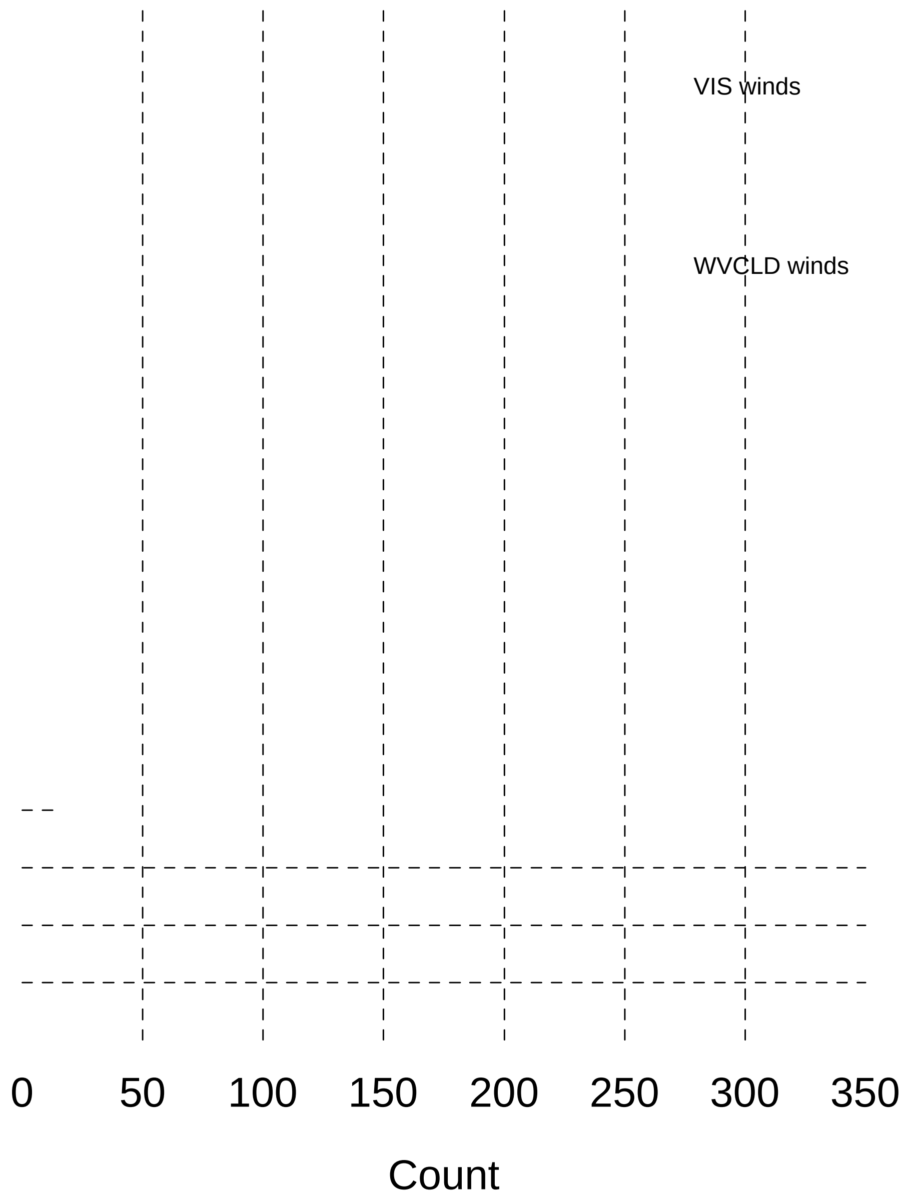


Figure 12: (continued)


VIS winds
WVCLD winds
0
50
100
150
200
250
300
350
Count

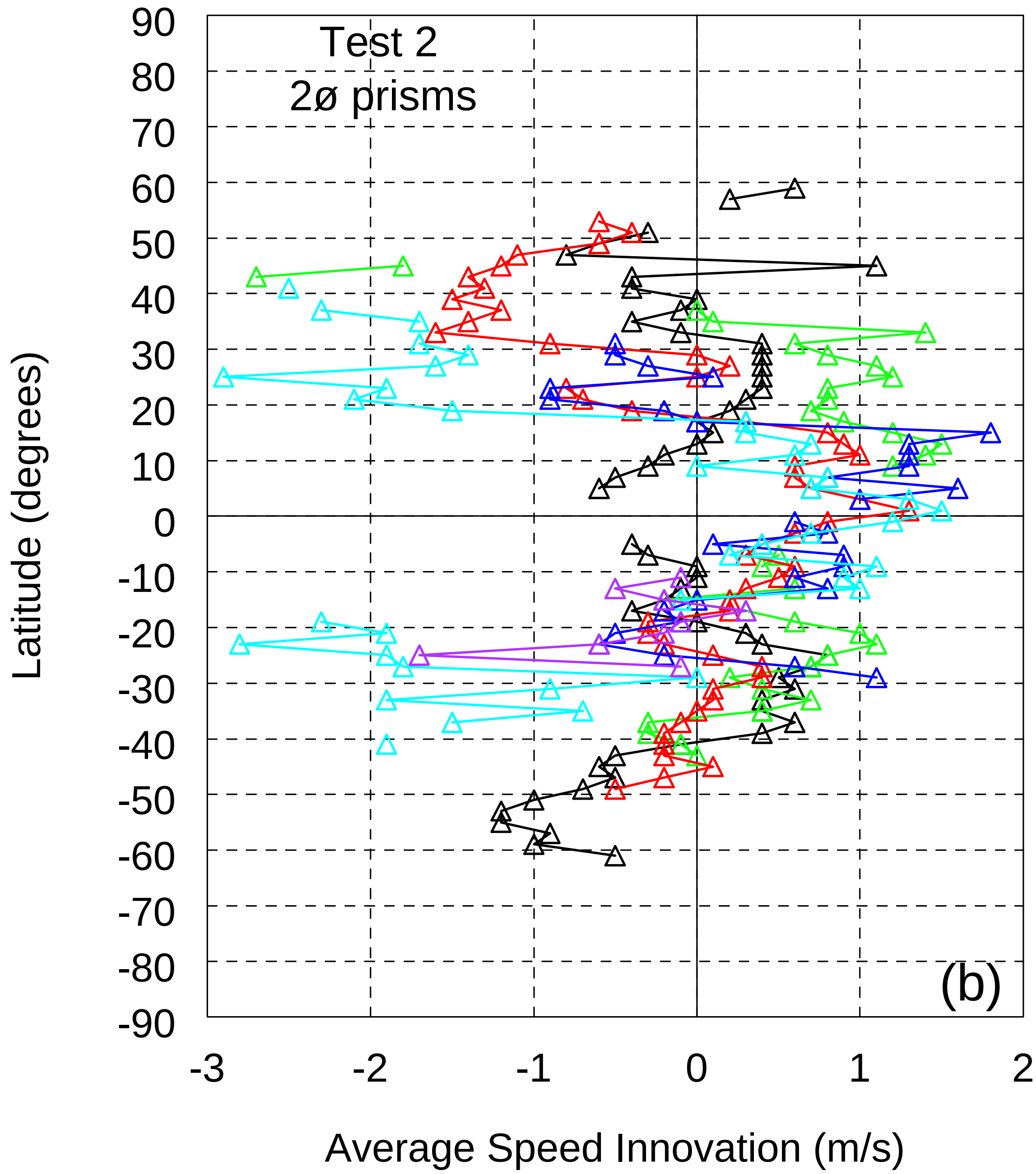


Figure 13: (continued)

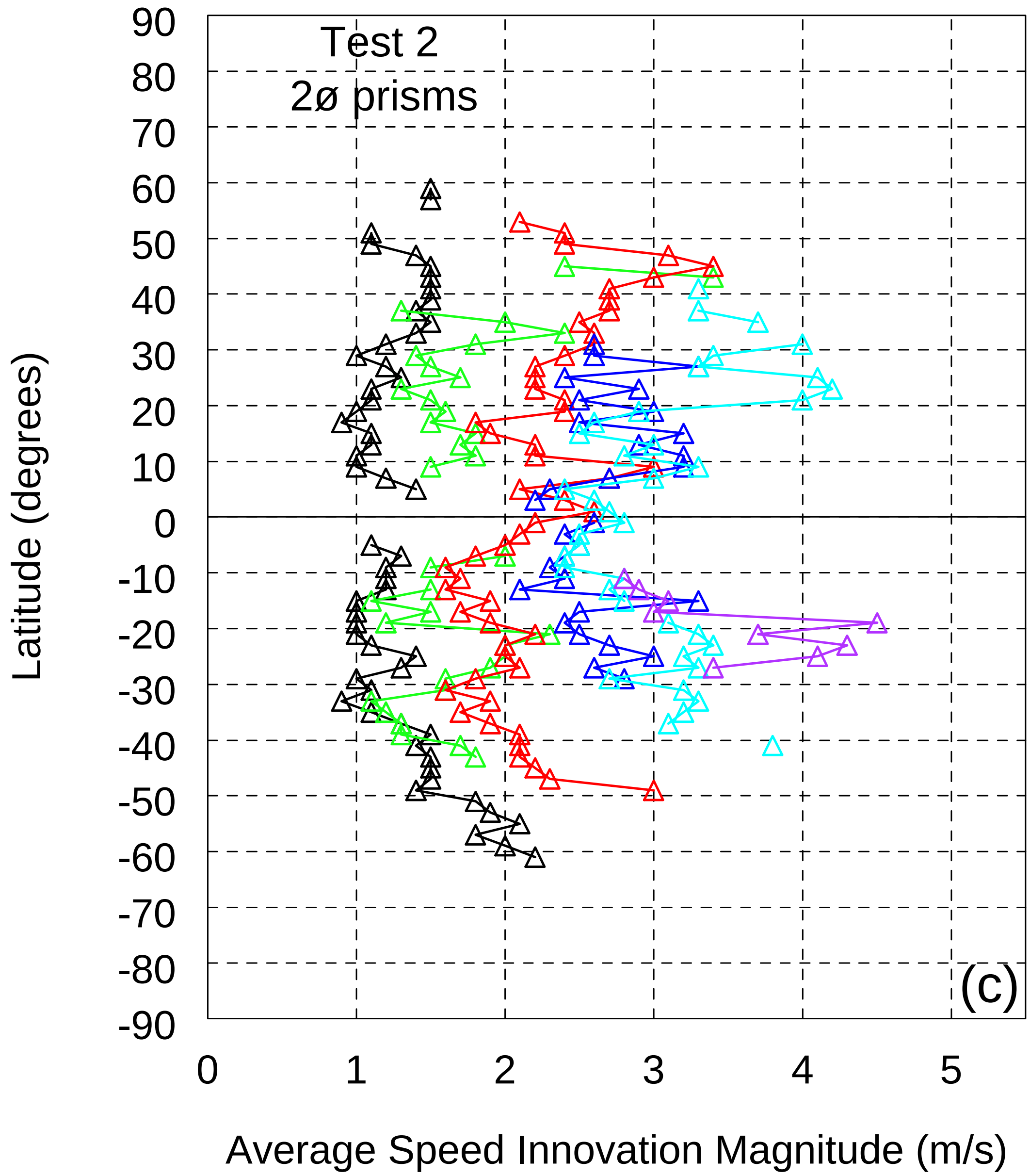


Figure 13: (continued)

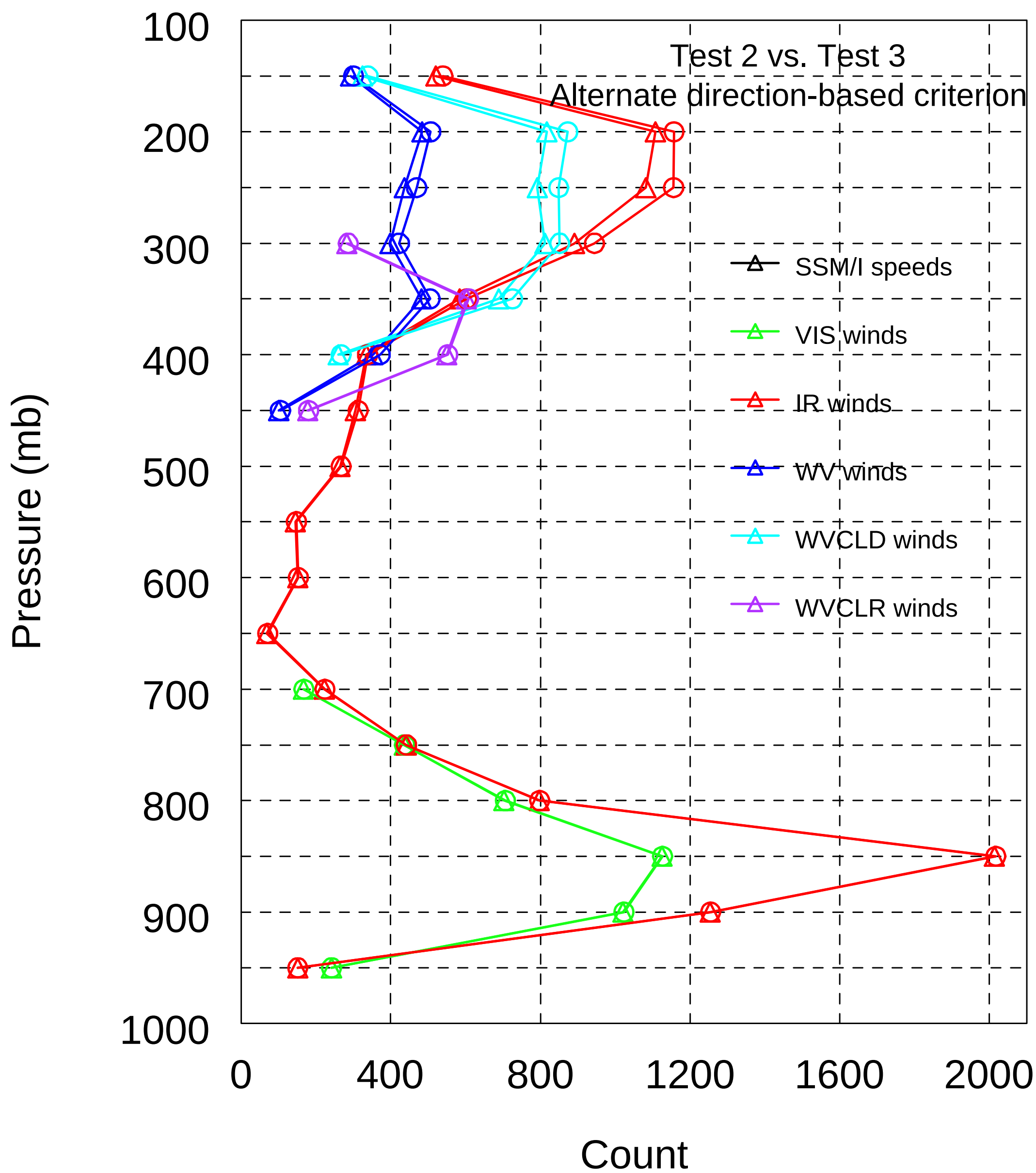


Figure 14: Superob count as a function of pressure level for various satellite wind data types. Superobs from Test 2 are shown as open triangles, and superobs from Test 3 (2E prisms with alternate direction-based criterion) are shown as open circles. Statistics for points with fewer than 50 superobs have been omitted.

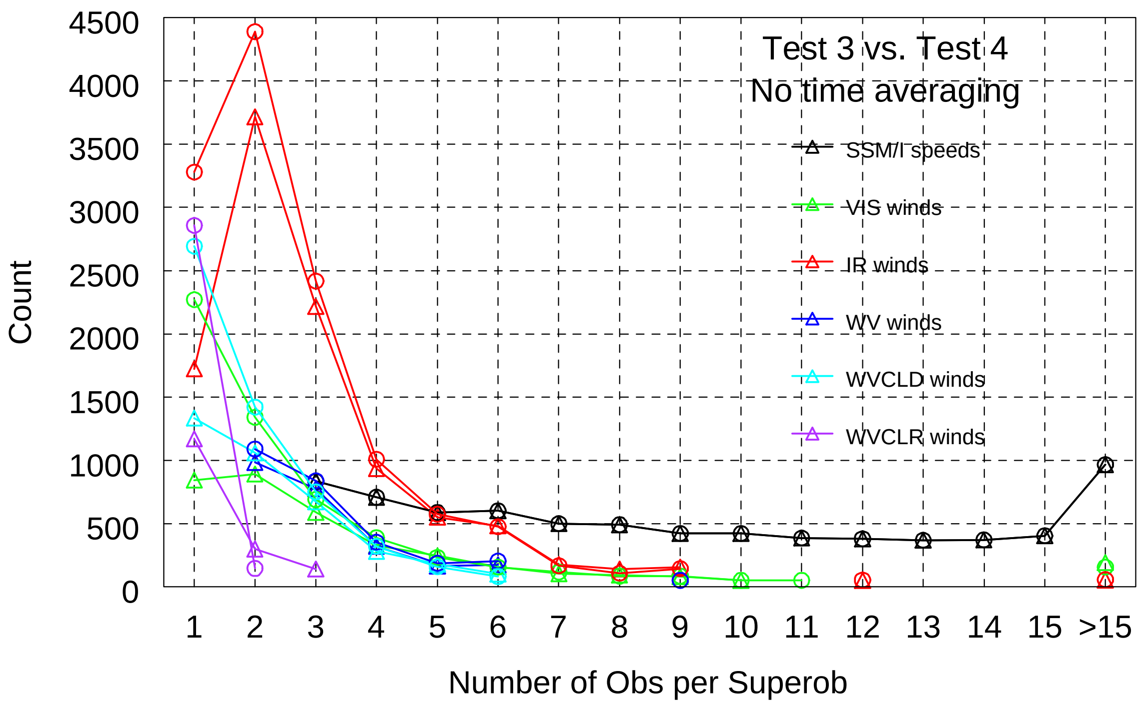


Figure 15: Superob count as a function of number of observations per superob for various satellite wind data types. Superobs from Test 3 are shown as open triangles, and superobs from Test 4 (no time averaging) are shown as open circles. Statistics for points with fewer than 50 superobs have been omitted.

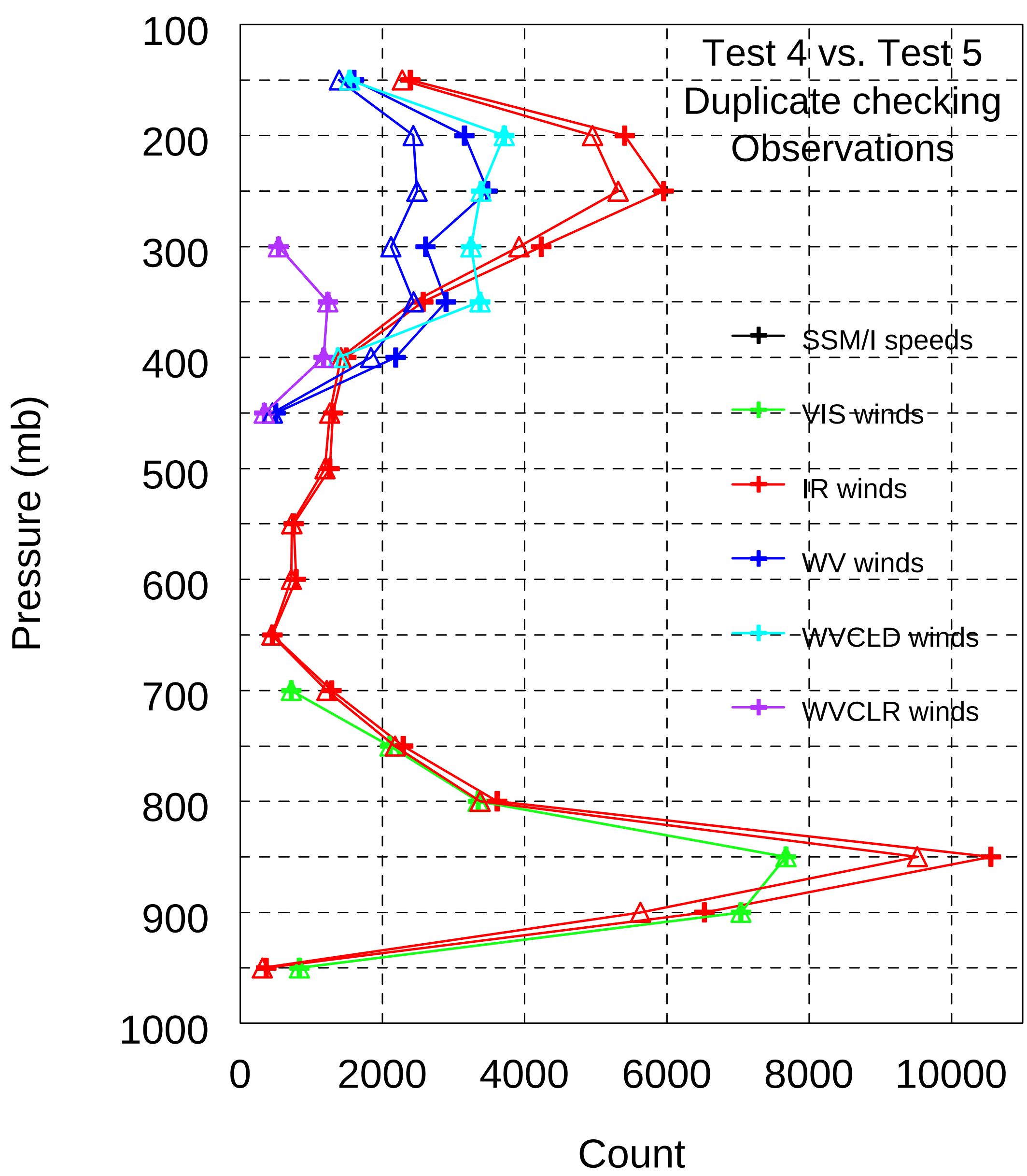


Figure 16: Observation count as a function of pressure level for various satellite wind data types. Observations from Test 4 are shown as plus signs, and observations from Test 5 (with duplicate checking) are shown as open triangles. Statistics for levels where these observations make fewer than 50 superobs have been omitted.

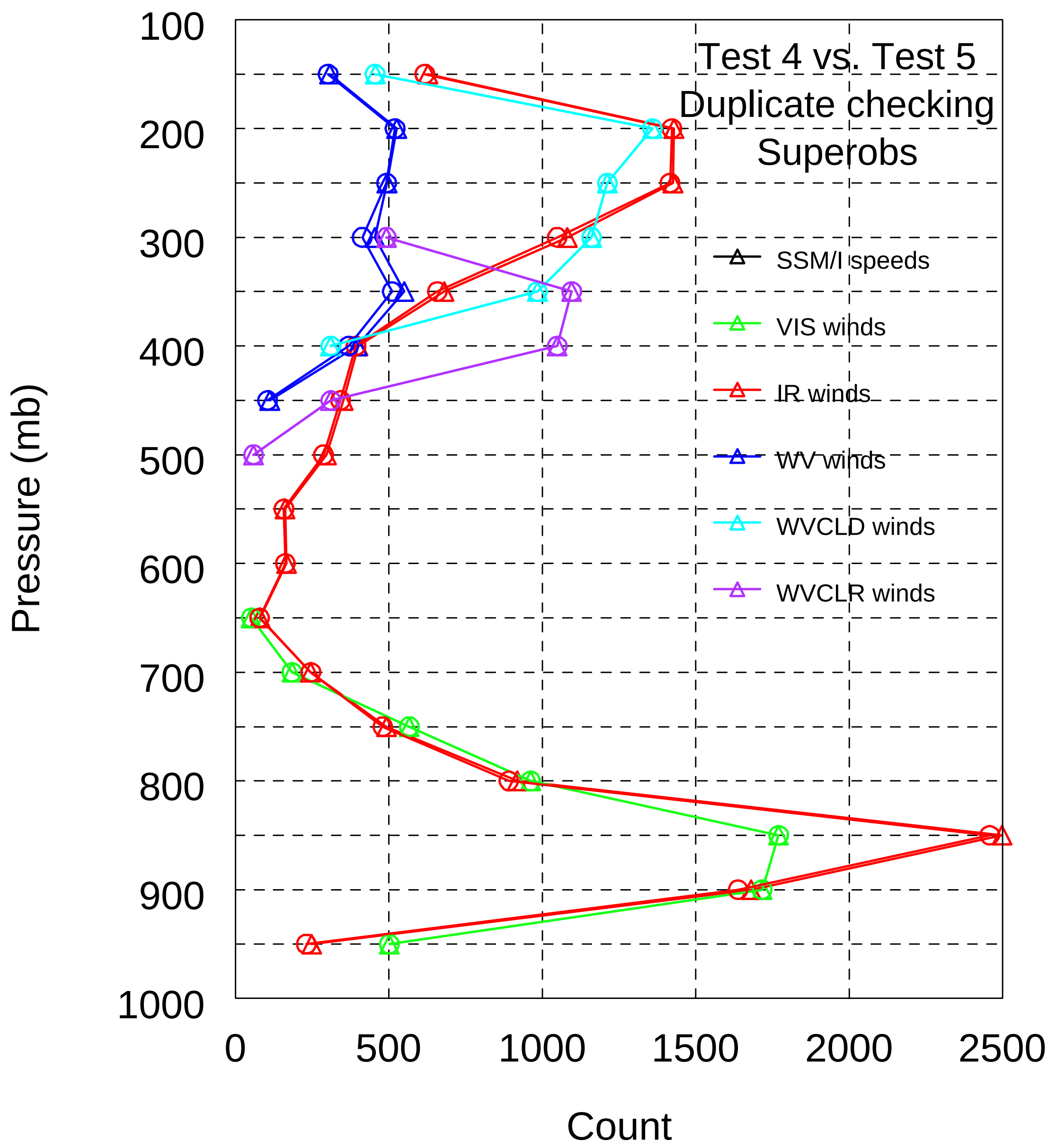


Figure 17: Superob count as a function of pressure level for various satellite wind data types. Superobs from Test 4 are shown as open triangles, and superobs from Test 5 (with duplicate checking) are shown as open circles. Statistics for points with fewer than 50 superobs have been omitted.

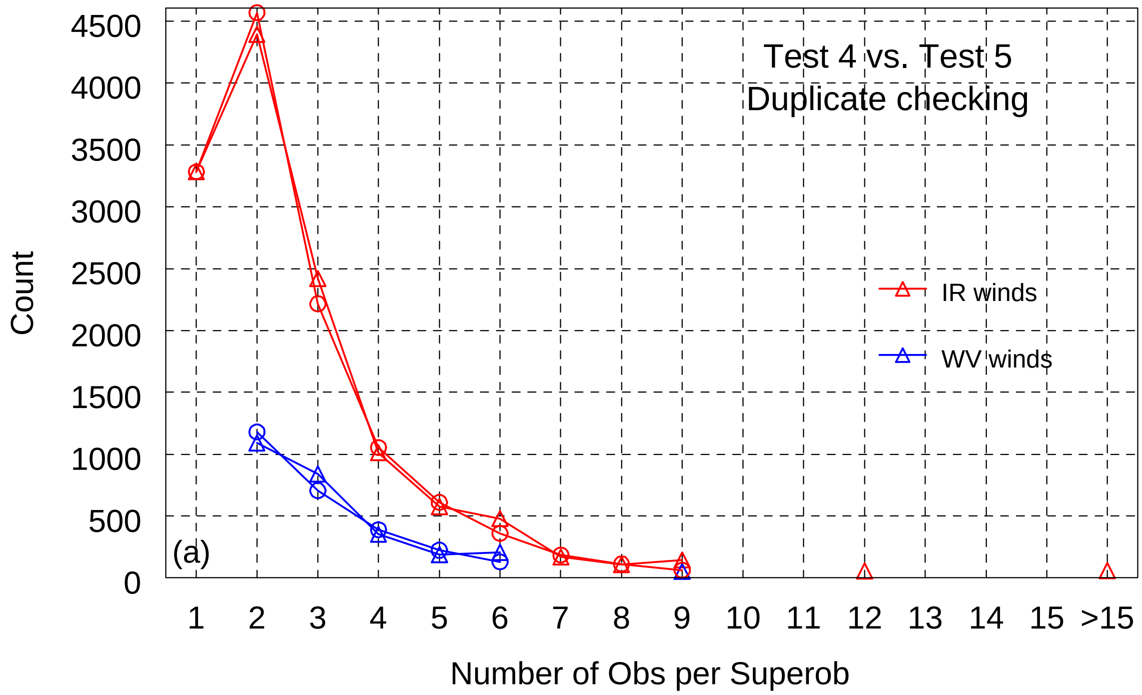


Figure 18: (a) Superob count, (b) average speed innovation (m/s), and (c) average magnitude of the speed innovation (m/s) as a function of number of observations per superob for IR and WV satellite winds. Superobs from Test 4 are shown as open triangles, and superobs from Test 5 (with duplicate checking) are shown as open circles. Statistics for points with fewer than 50 superobs have been omitted.

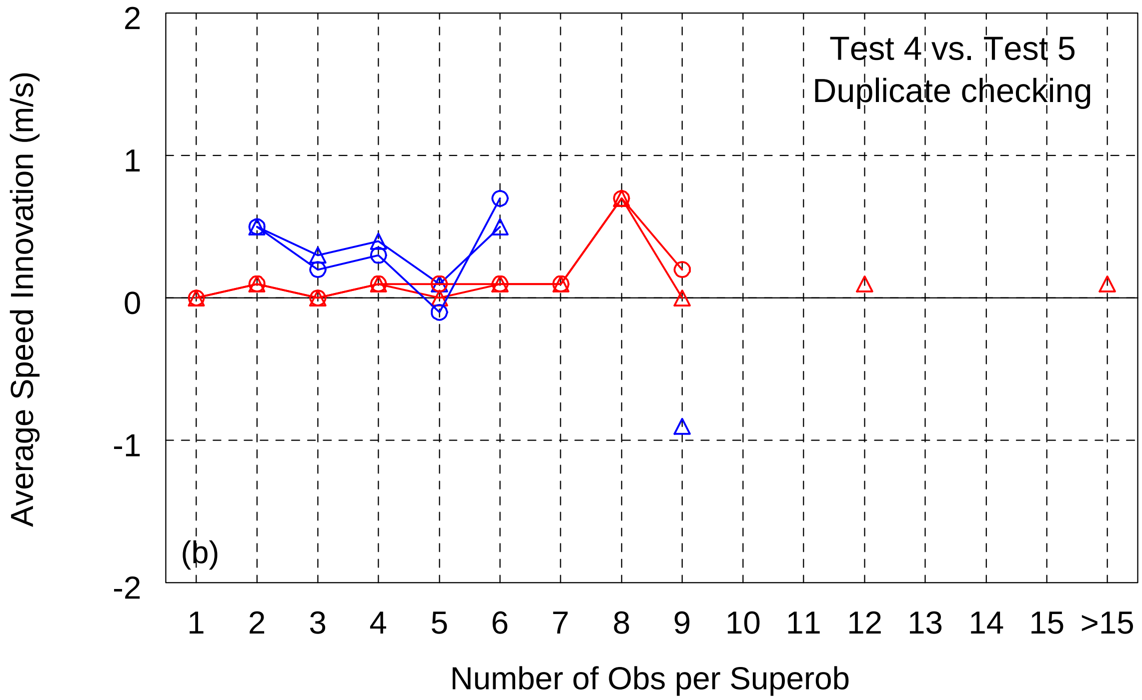


Figure 18: (continued)

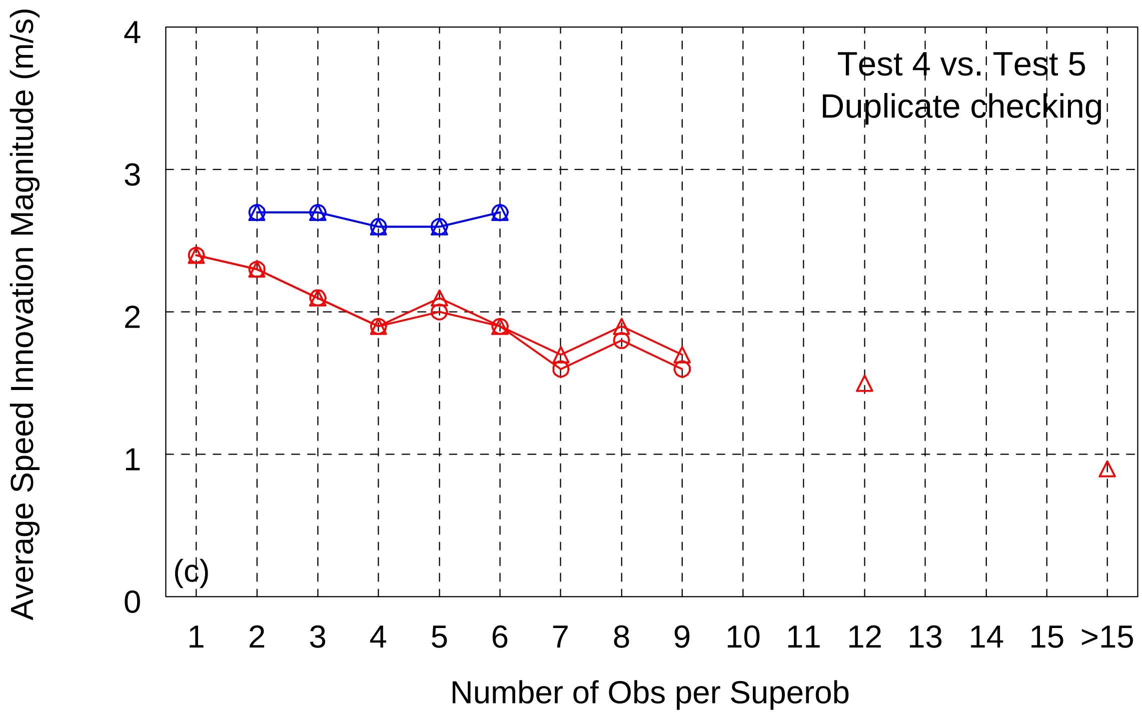


Figure 18: (continued)

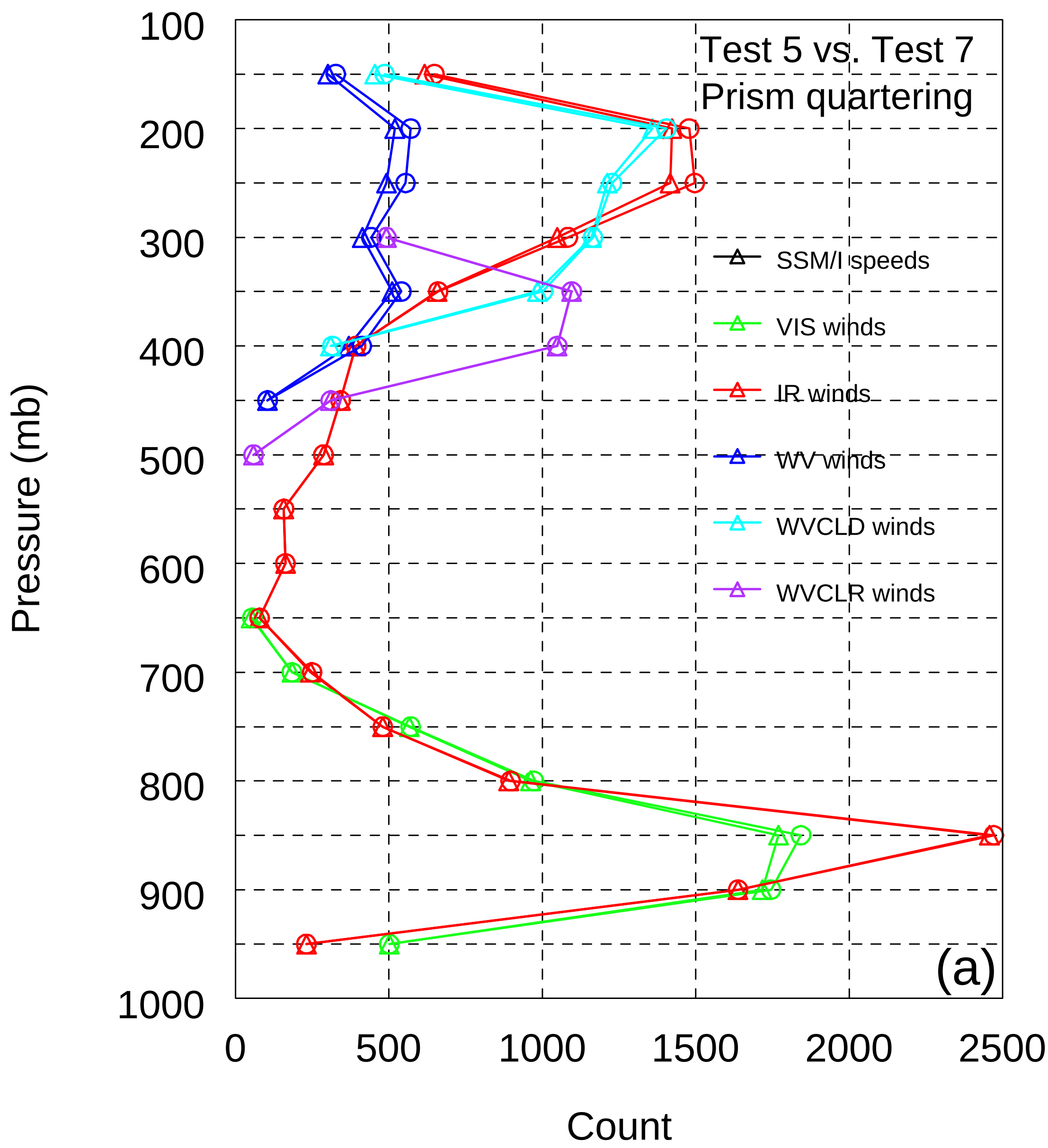


Figure 19: Same as Fig. 5, except superobs from Test 5 are shown as open triangles, and superobs from Test 7 (with prism quartering) are shown as open circles.

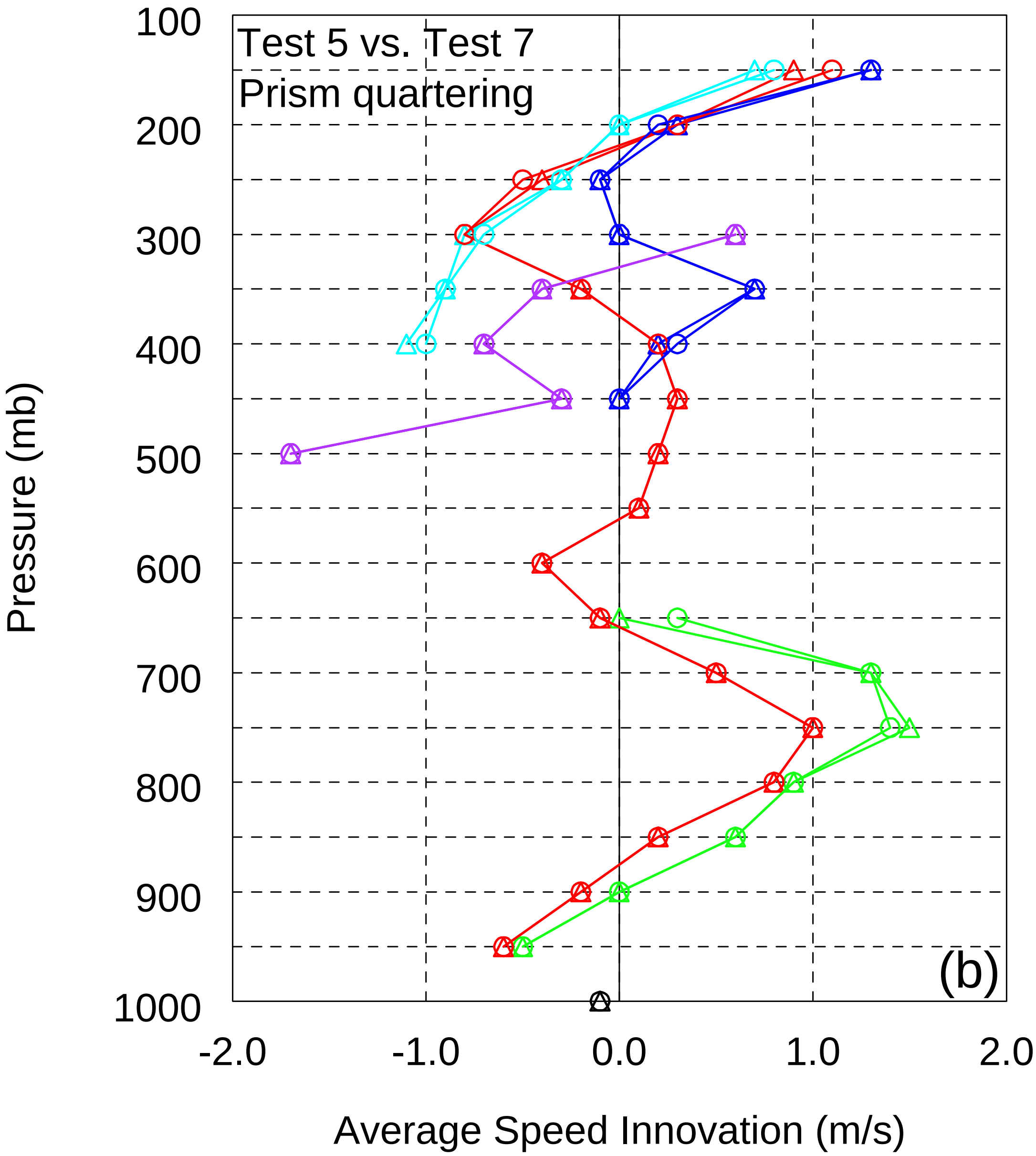


Figure 19: (continued)

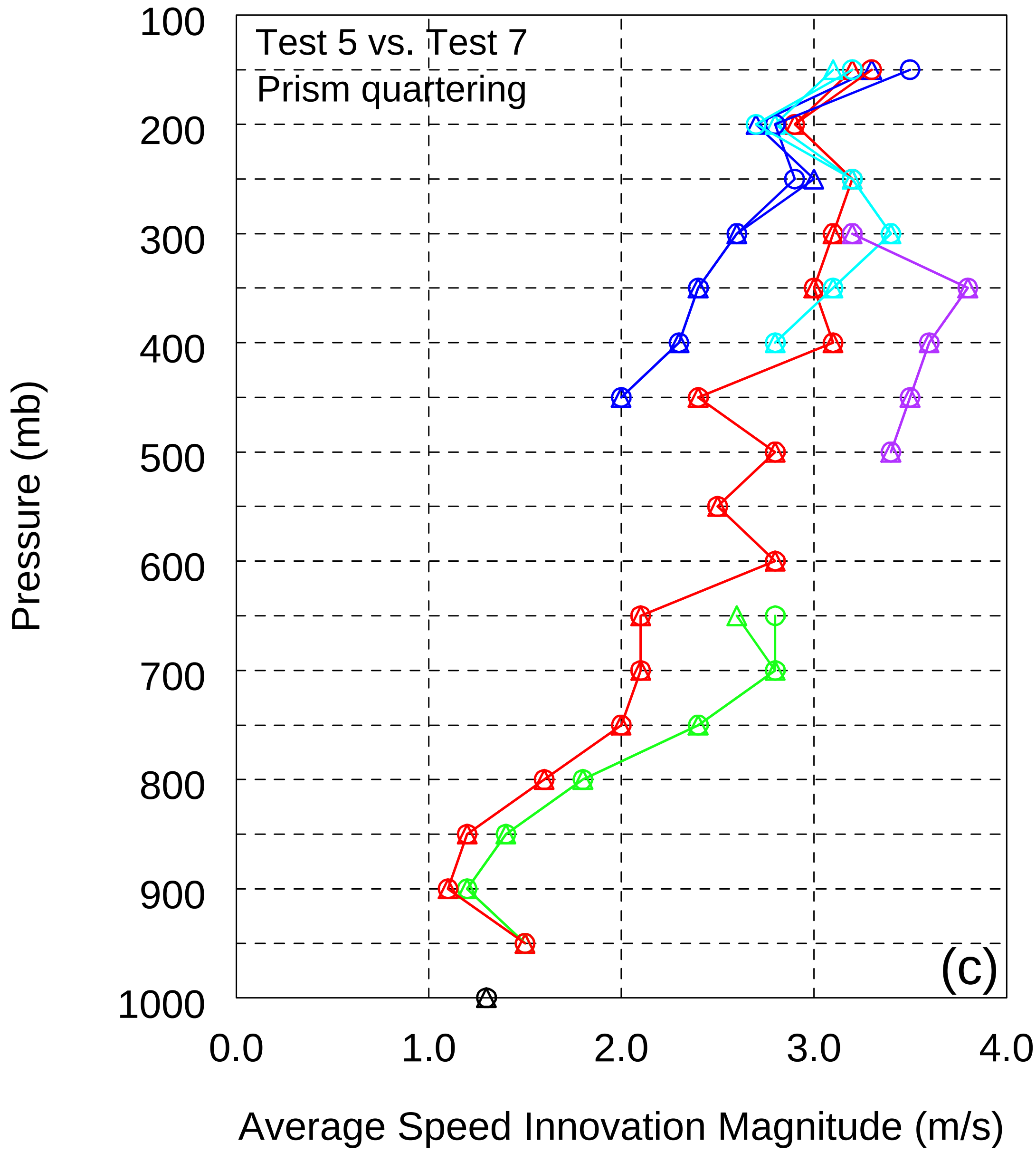


Figure 19: (continued)

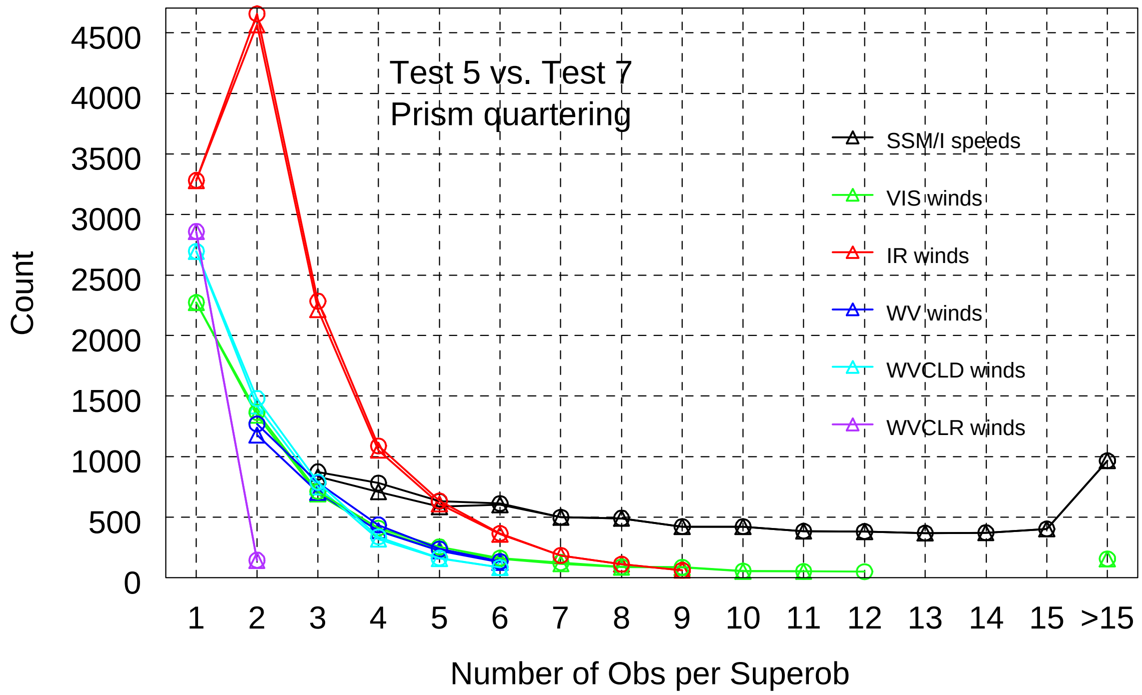


Figure 20: Same as Fig. 15, except superobs from Test 5 are shown as open triangles, and superobs from Test 7 (prism quartering) are shown as open circles.

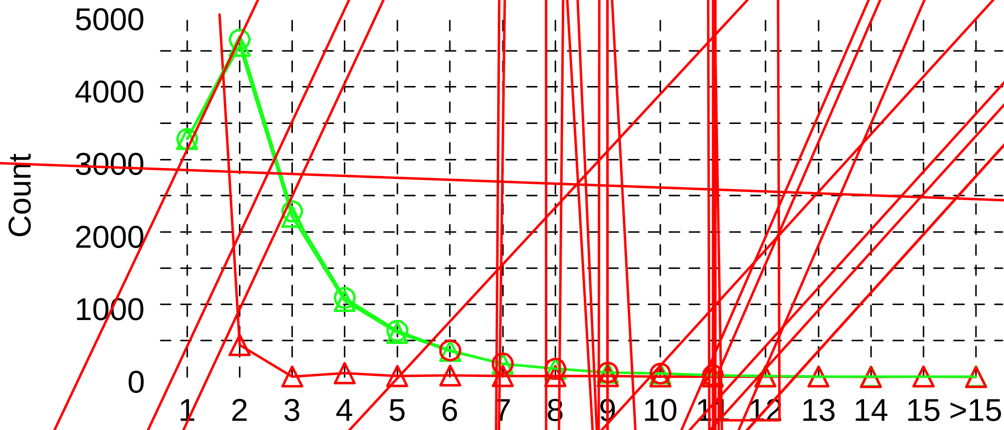
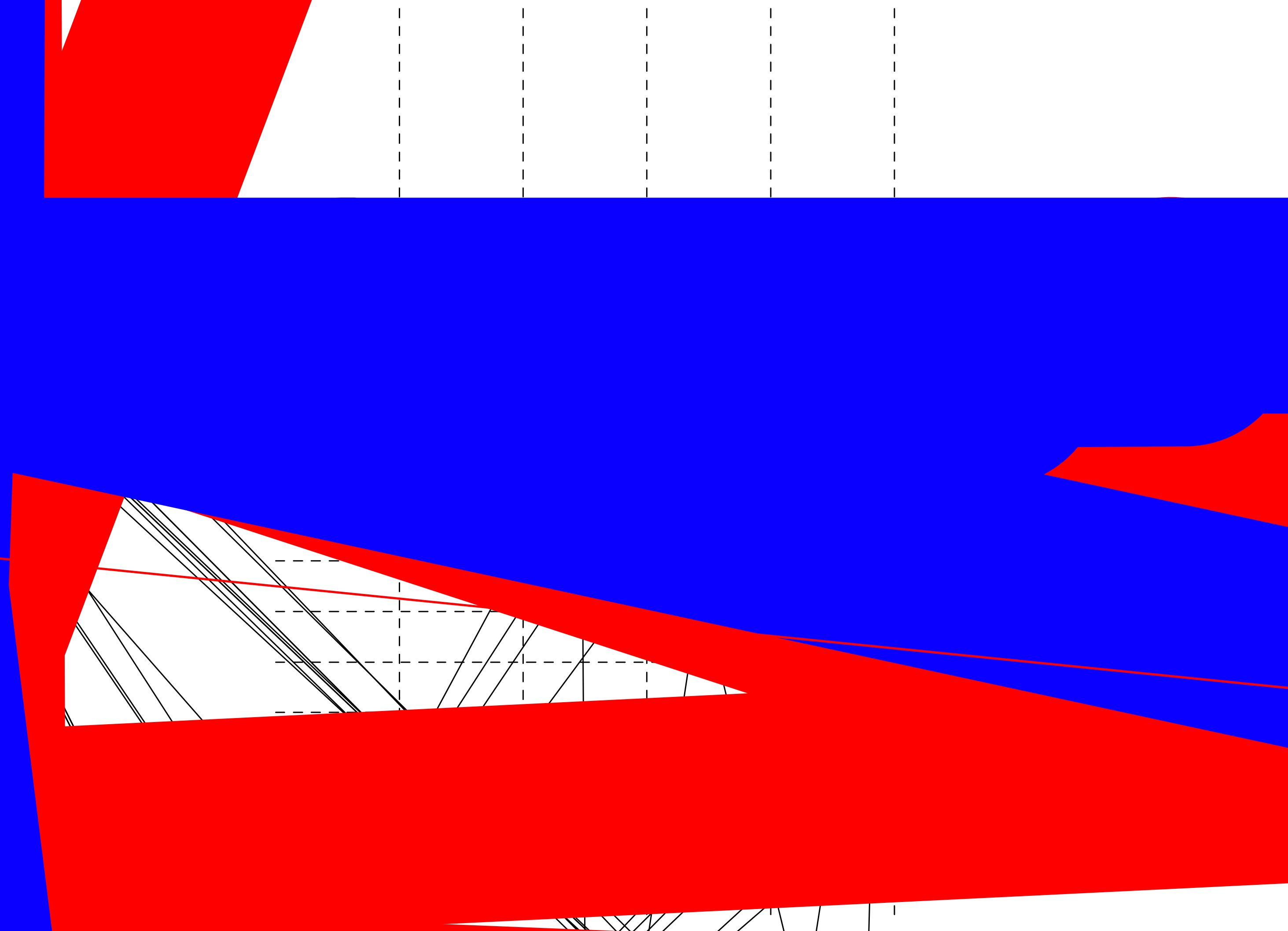


Figure 21: Superob count (top), average speed innovation (m/s) (center), and average magnitude of the speed innovation (m/s) (bottom) as a function of number of observations per superob for IR winds with (circles) and without (triangles) prism quartering. Values with counts greater than 10 are plotted.



various

7 values minus Test 5 values. Differences were

ter show the effects of prism quartering.

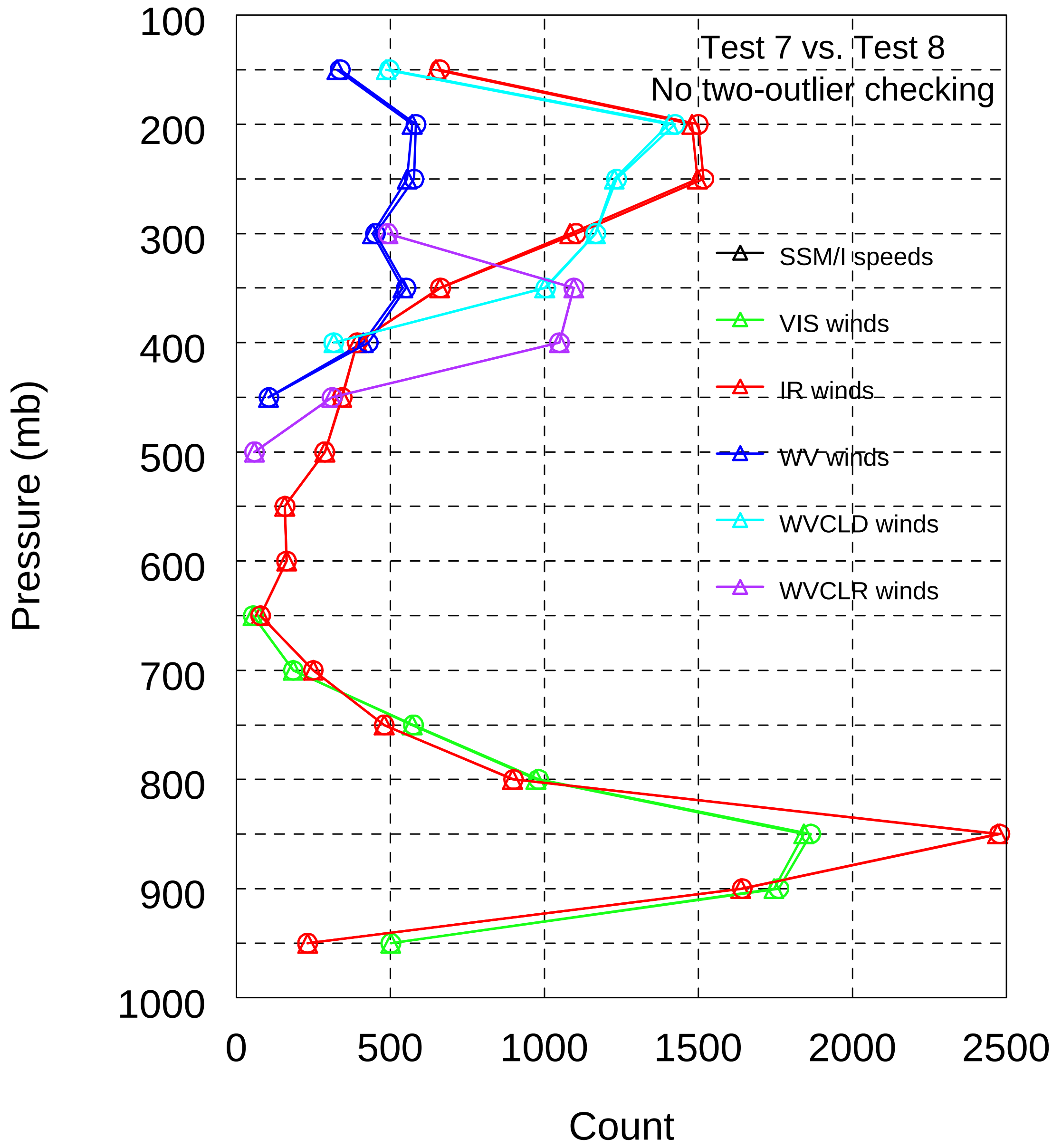


Figure 23: Same as Fig. 17, except superobs from Test 7are shown as open triangles, and superobs from Test 8 (without two-outlier checking) are shown as open circles.

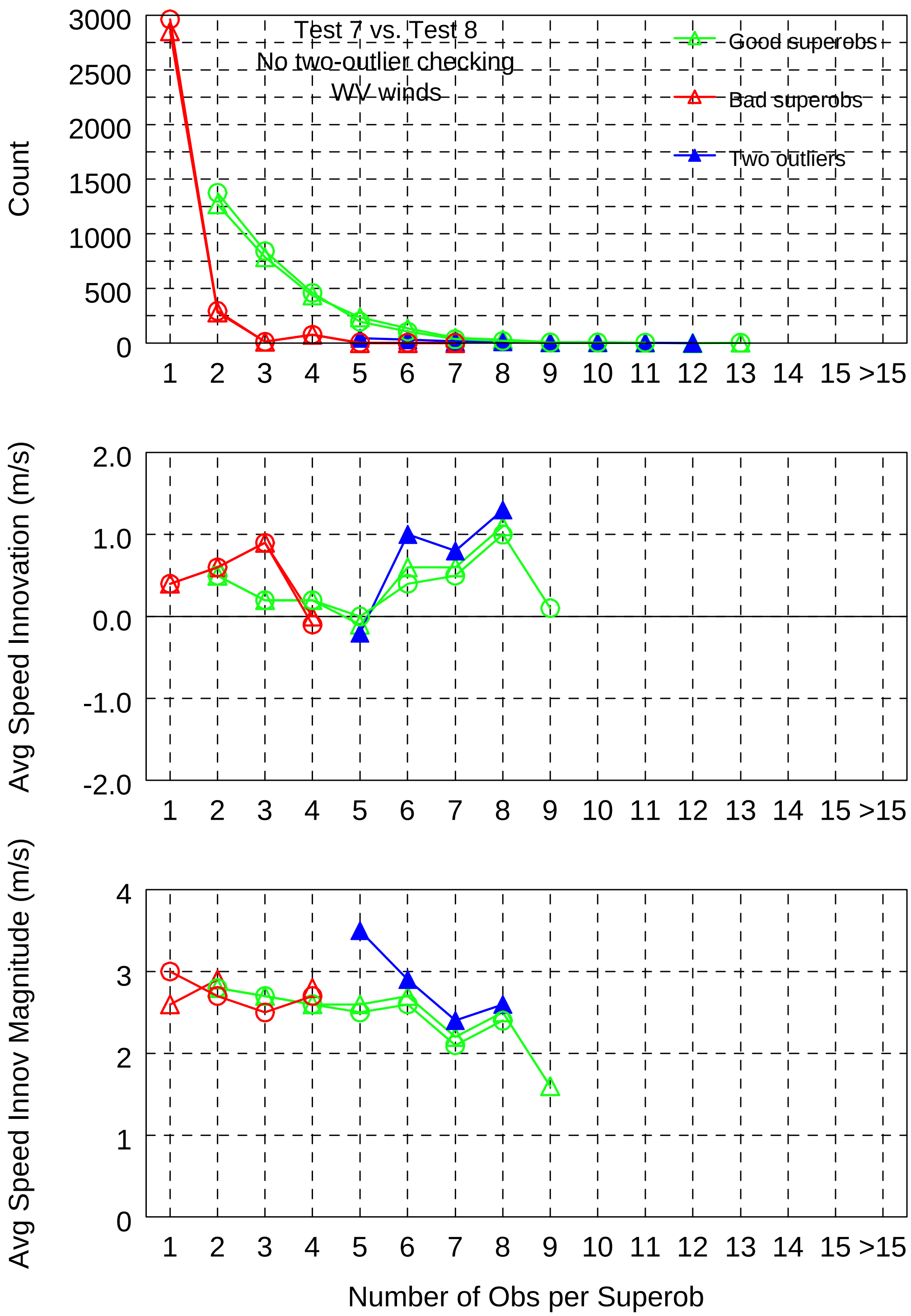


Figure 24: Same as Fig. 21 except for WV winds with (triangles) and without (circles) two-outlier checking.

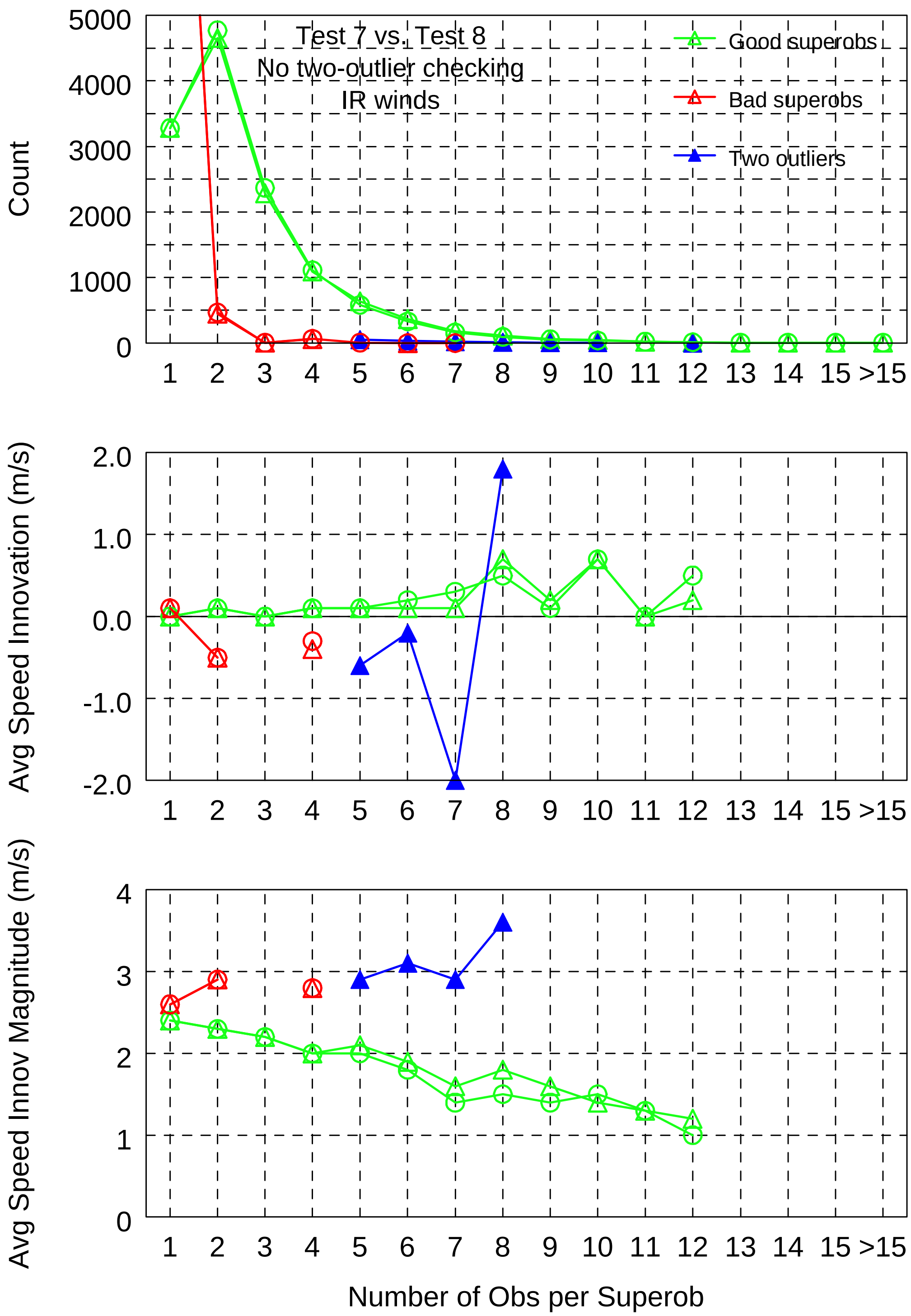


Figure 25: Same as Fig. 21 except for IR winds with (triangles) and without (circles) two-outlier checking.

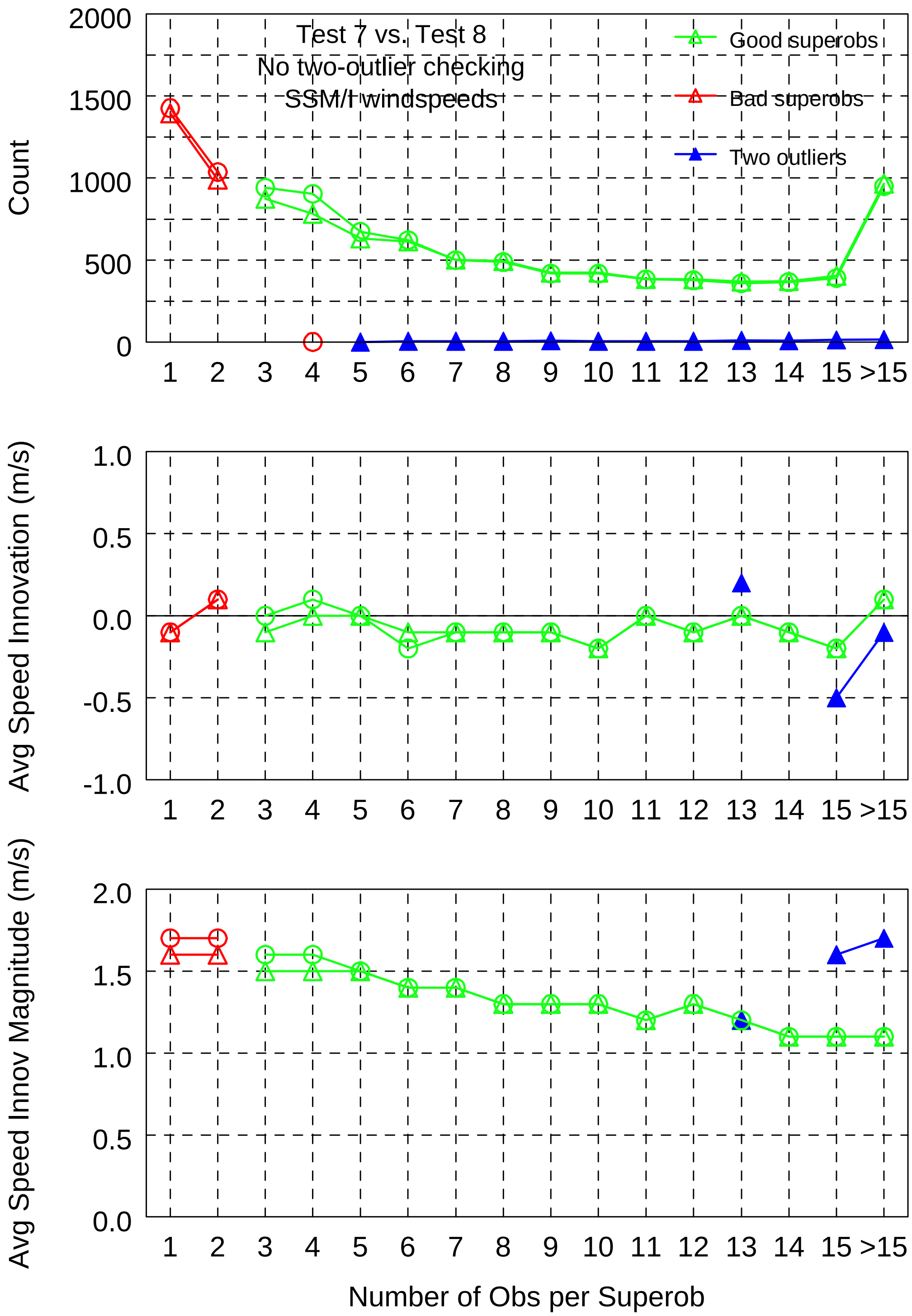


Figure 26: Same as Fig. 21 except for SSM/I windspeeds with (triangles) and without (circles) two-outlier checking.

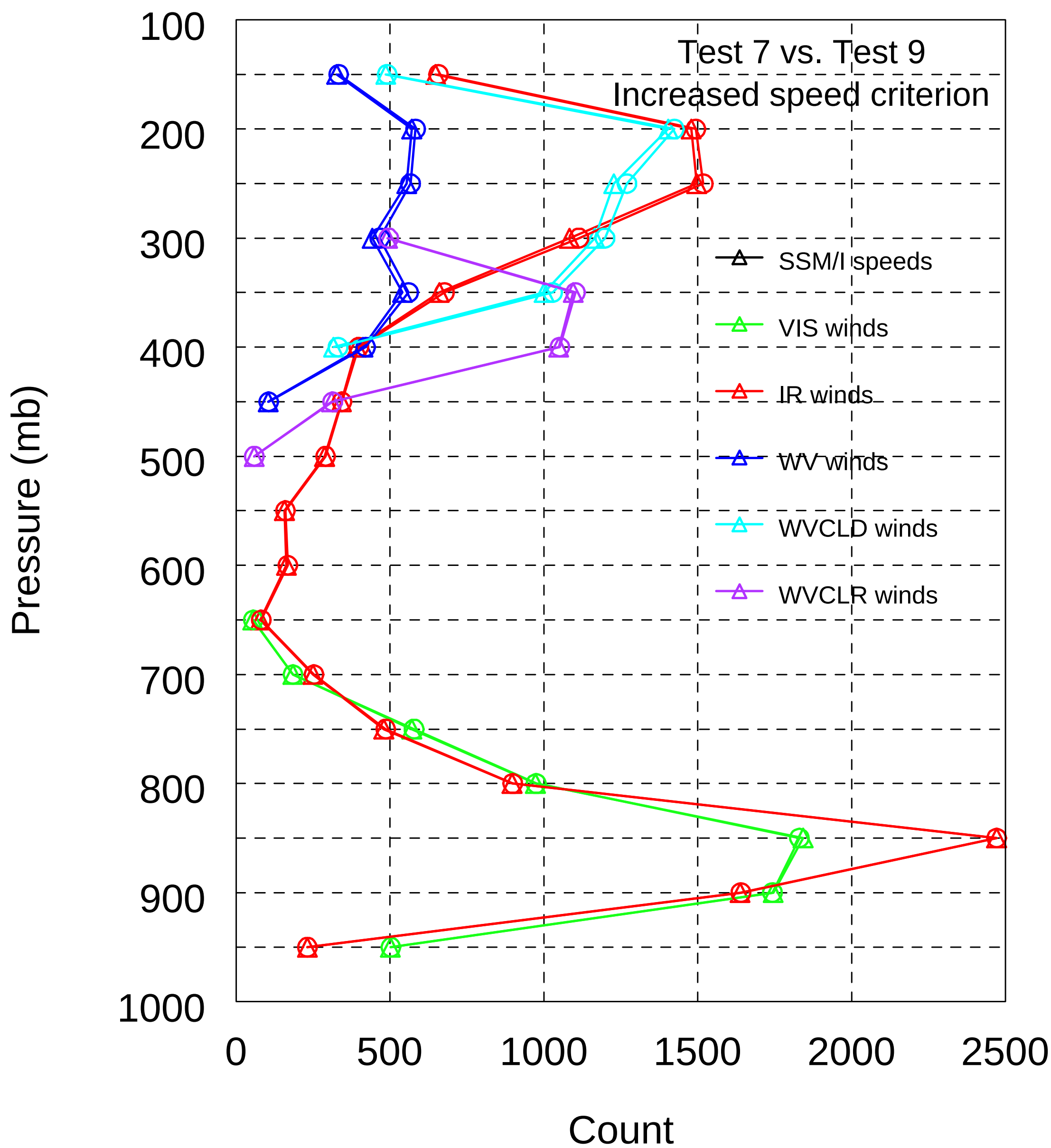


Figure 27: Same as Fig. 17, except superobs from Test 7are shown as open triangles, and superobs from Test 9 (with 7 m/s speed criterion) are shown as open circles.

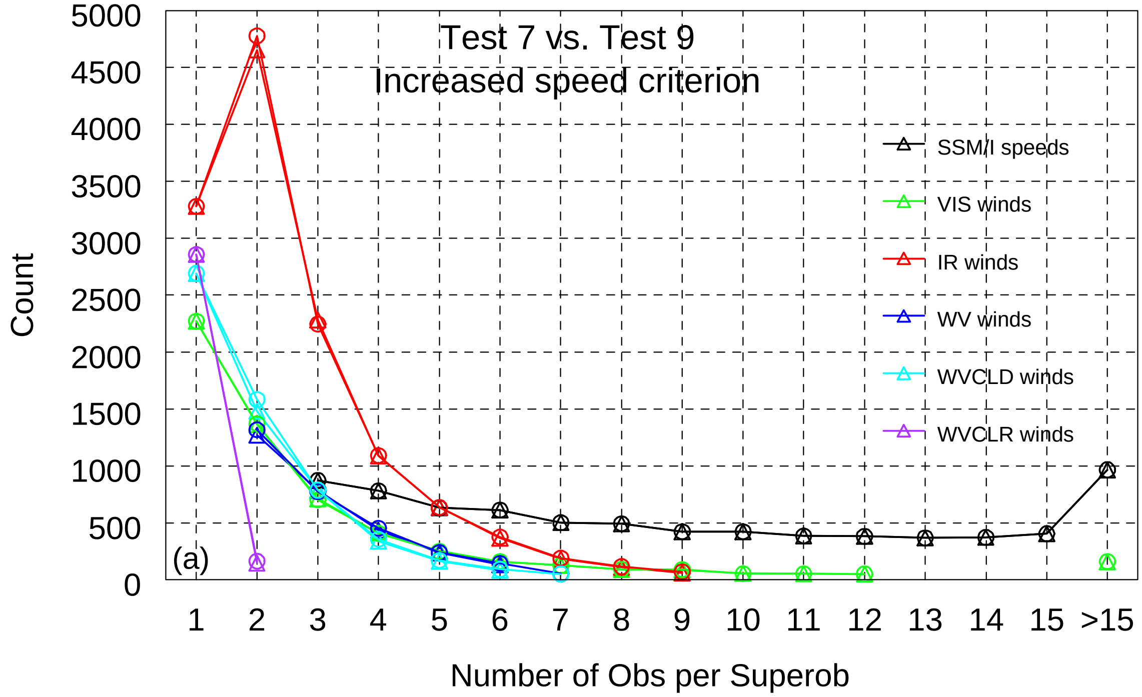


Figure 28: Same as Fig. 12, except superobs from Test 7 are shown as open triangles, and superobs from Test 9 (increased speed criterion) are shown as open circles

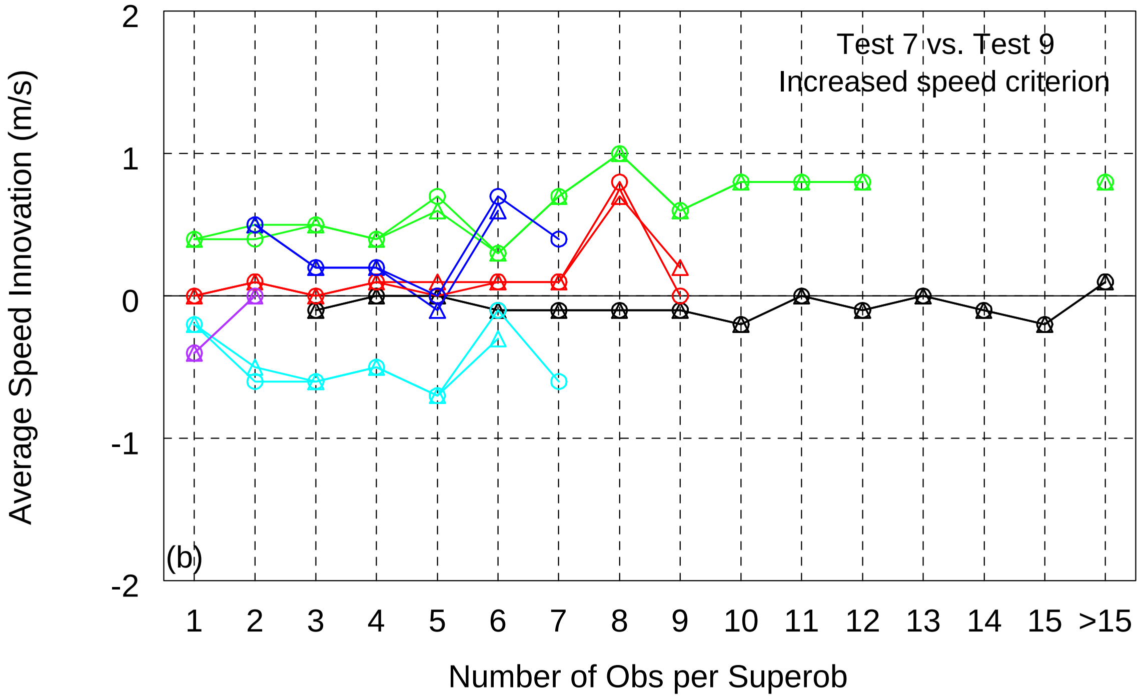


Figure 28: (continued)

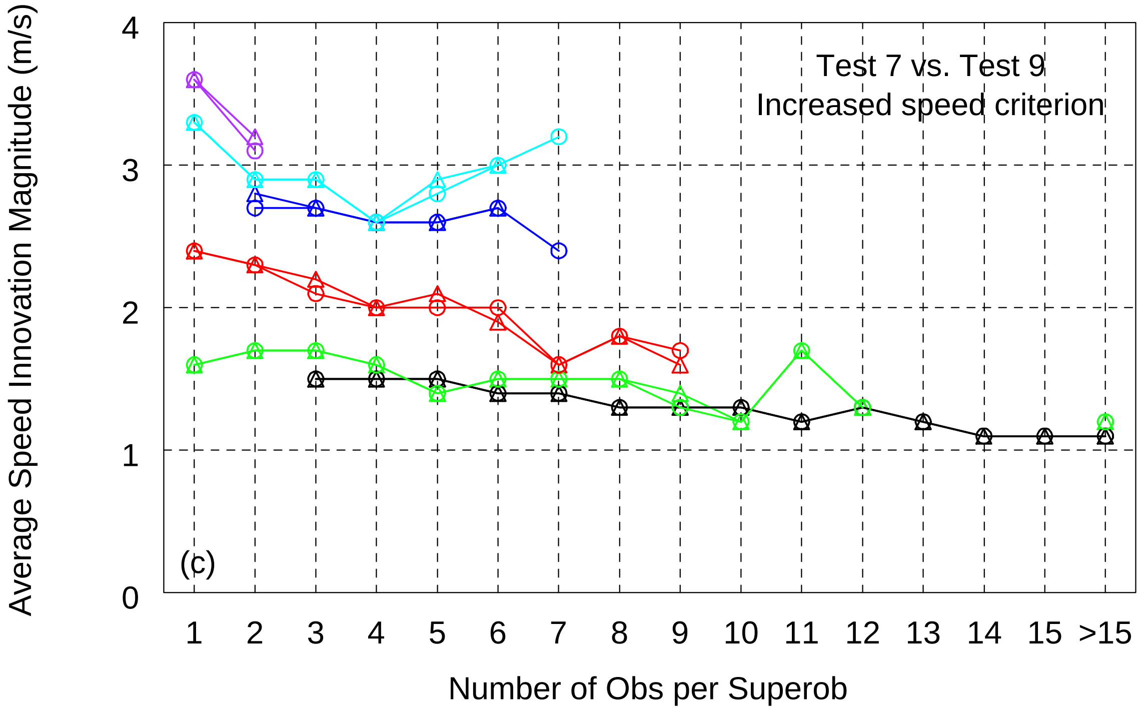


Figure 28: (continued)

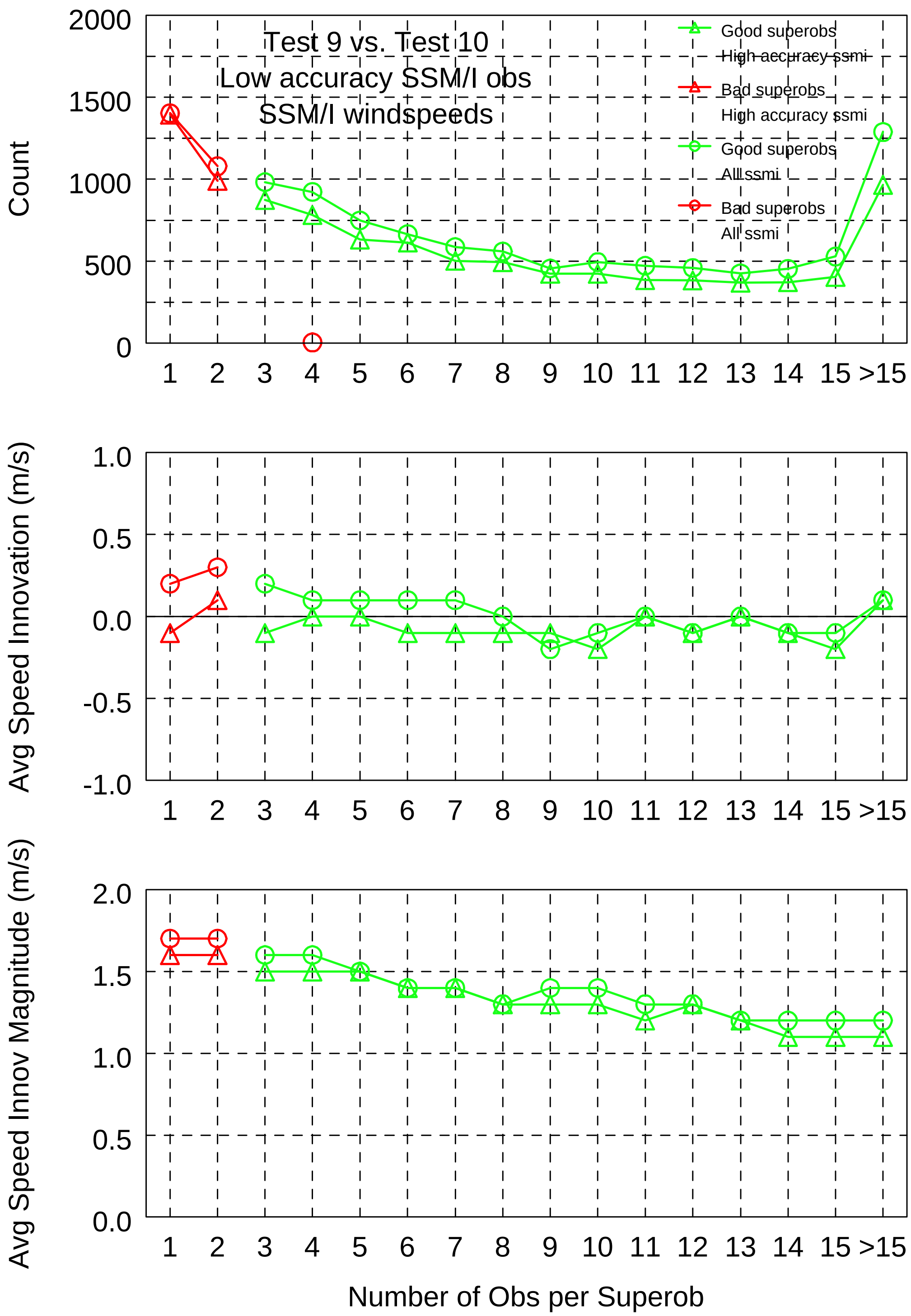


Figure 29: Same as Fig. 21, except for SSM/I windspeed superobs with (circles) and without (triangles) low-accuracy observations.

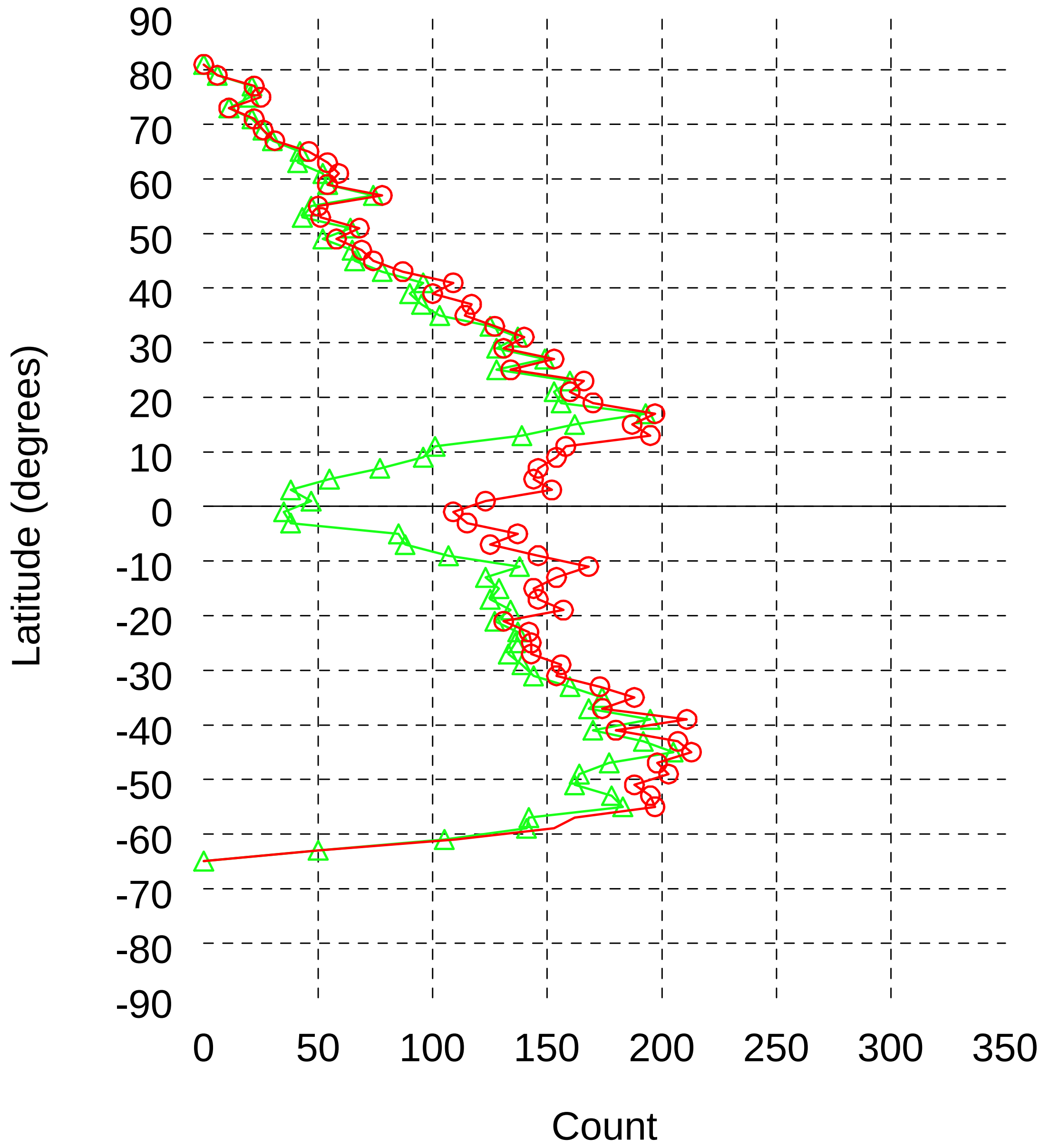


Figure 30: Same as Fig. 8 except for SSM/I windspeed superobs with (red circles) and without (green triangles) low accuracy observations.

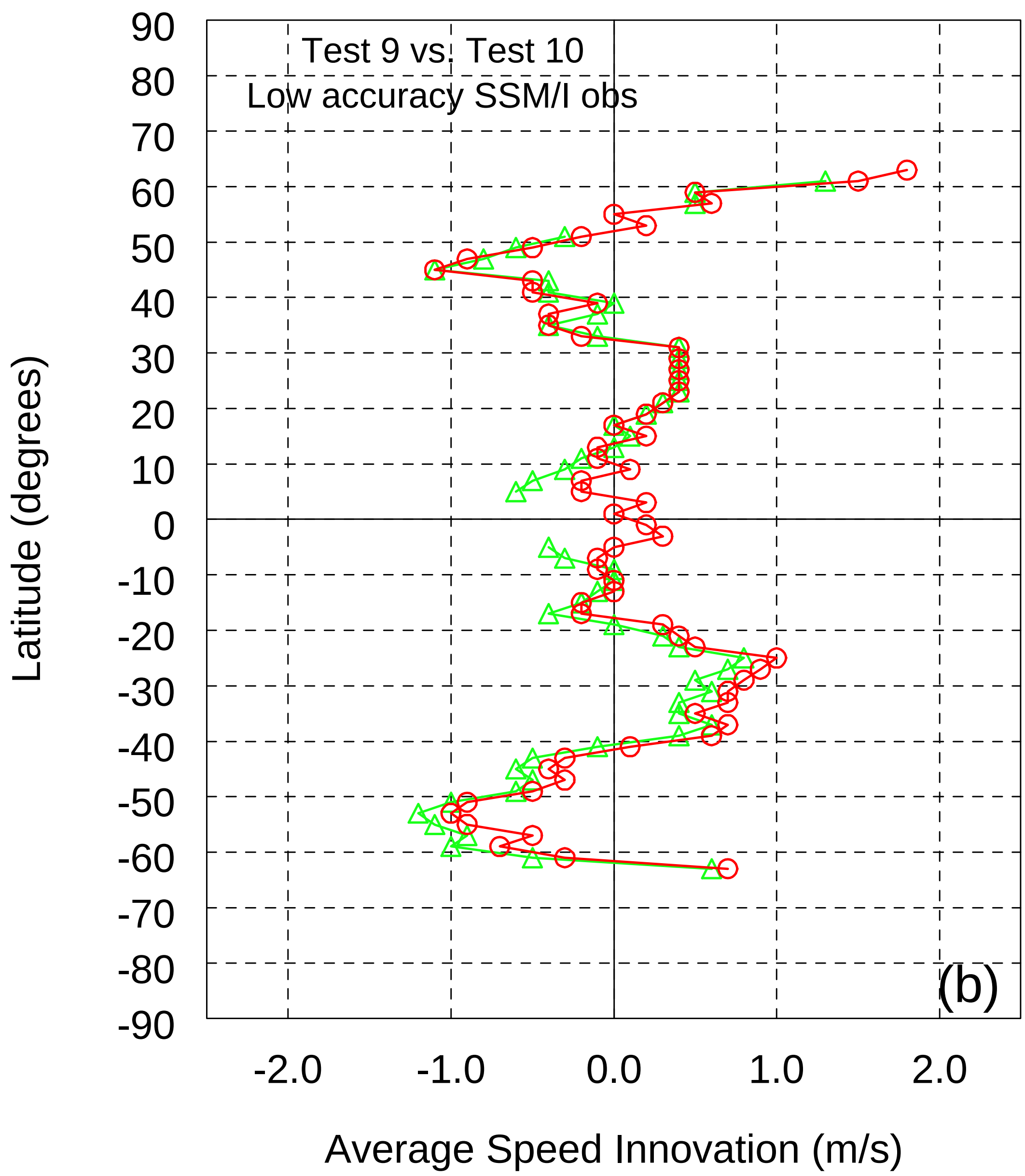


Figure 30: (continued)

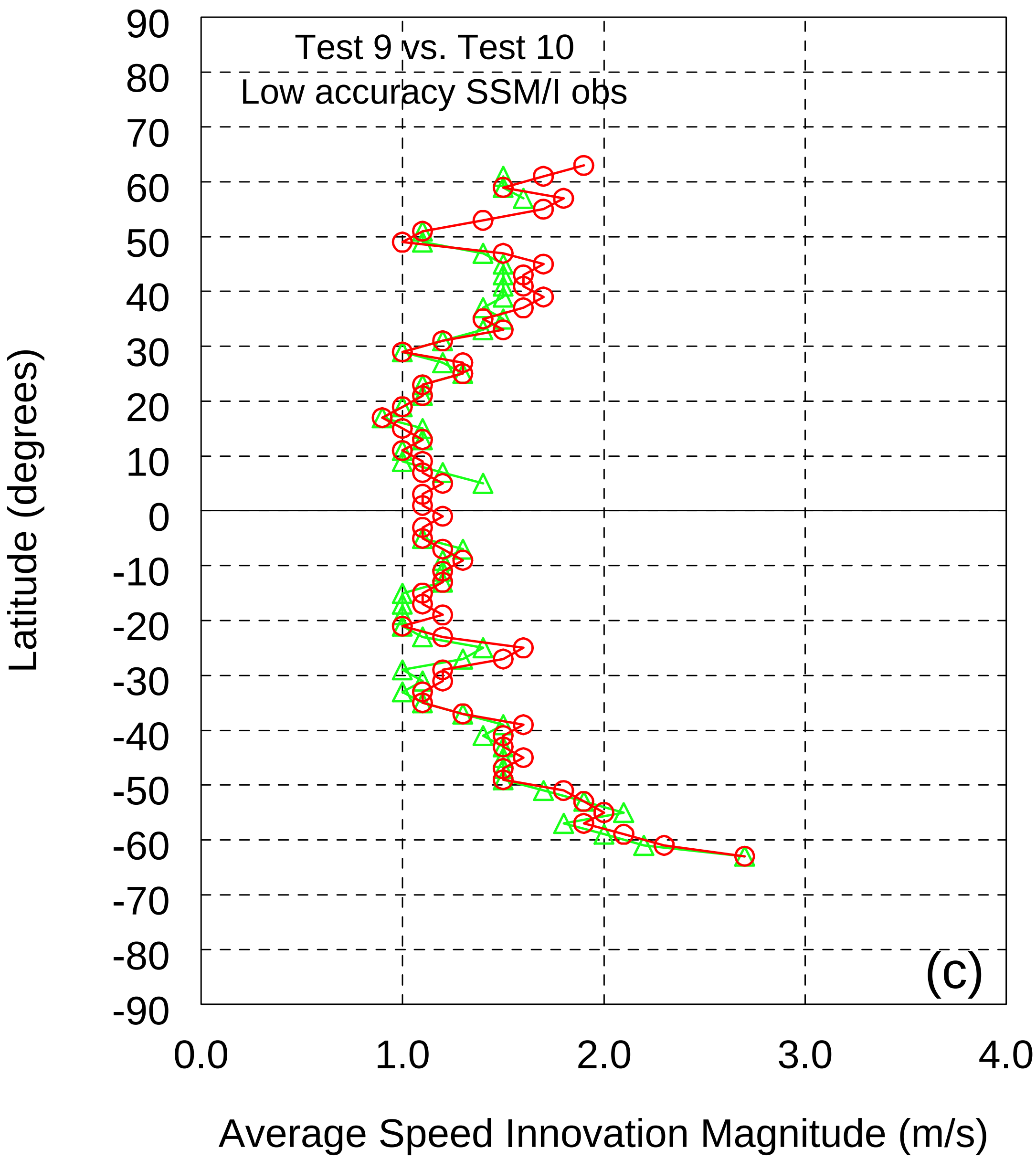


Figure 30: (continued)

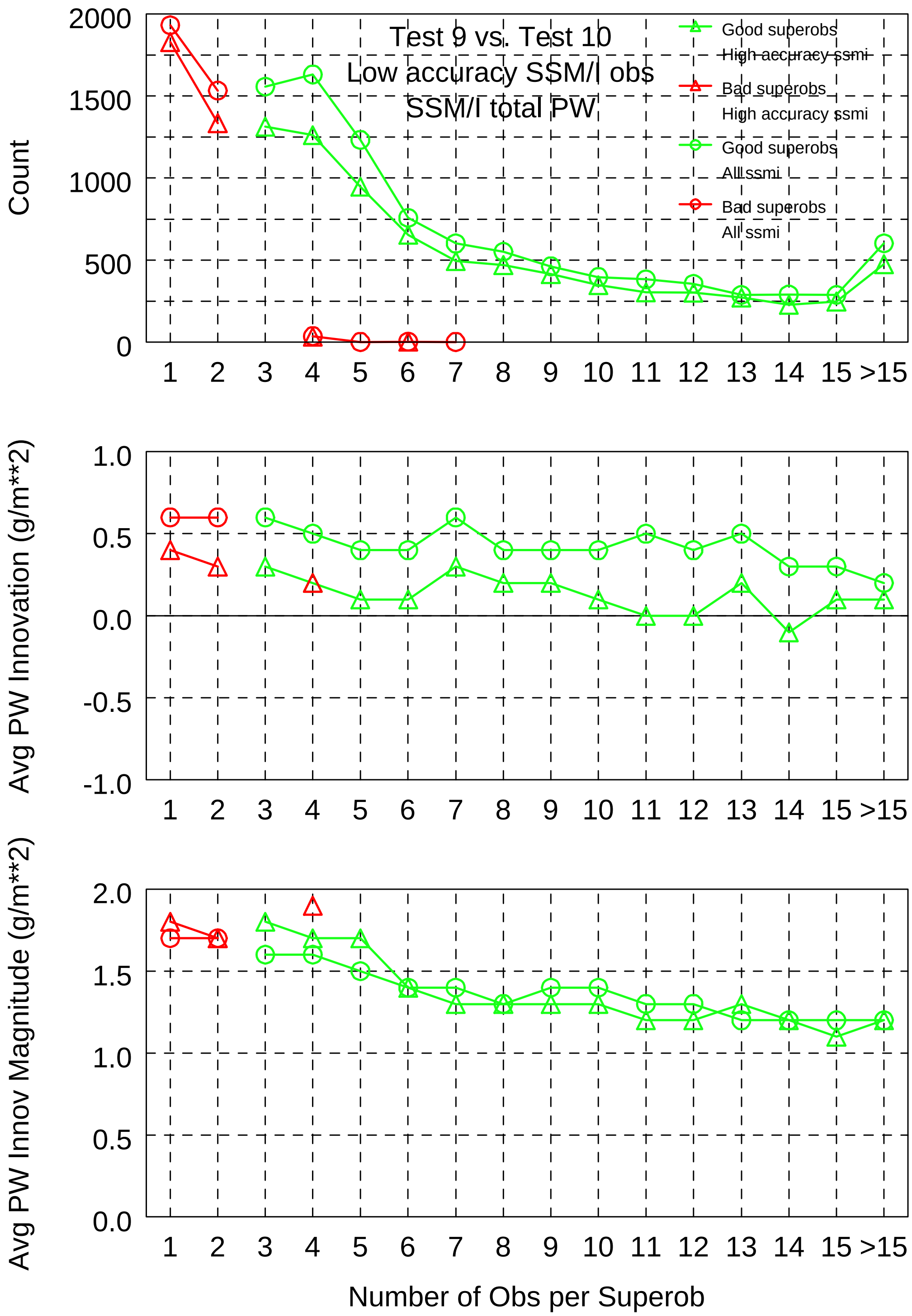


Figure 31: Same as Fig. 21, except for SSM/I precipitable water superobs with (circles) and without (triangles) low-accuracy observations.

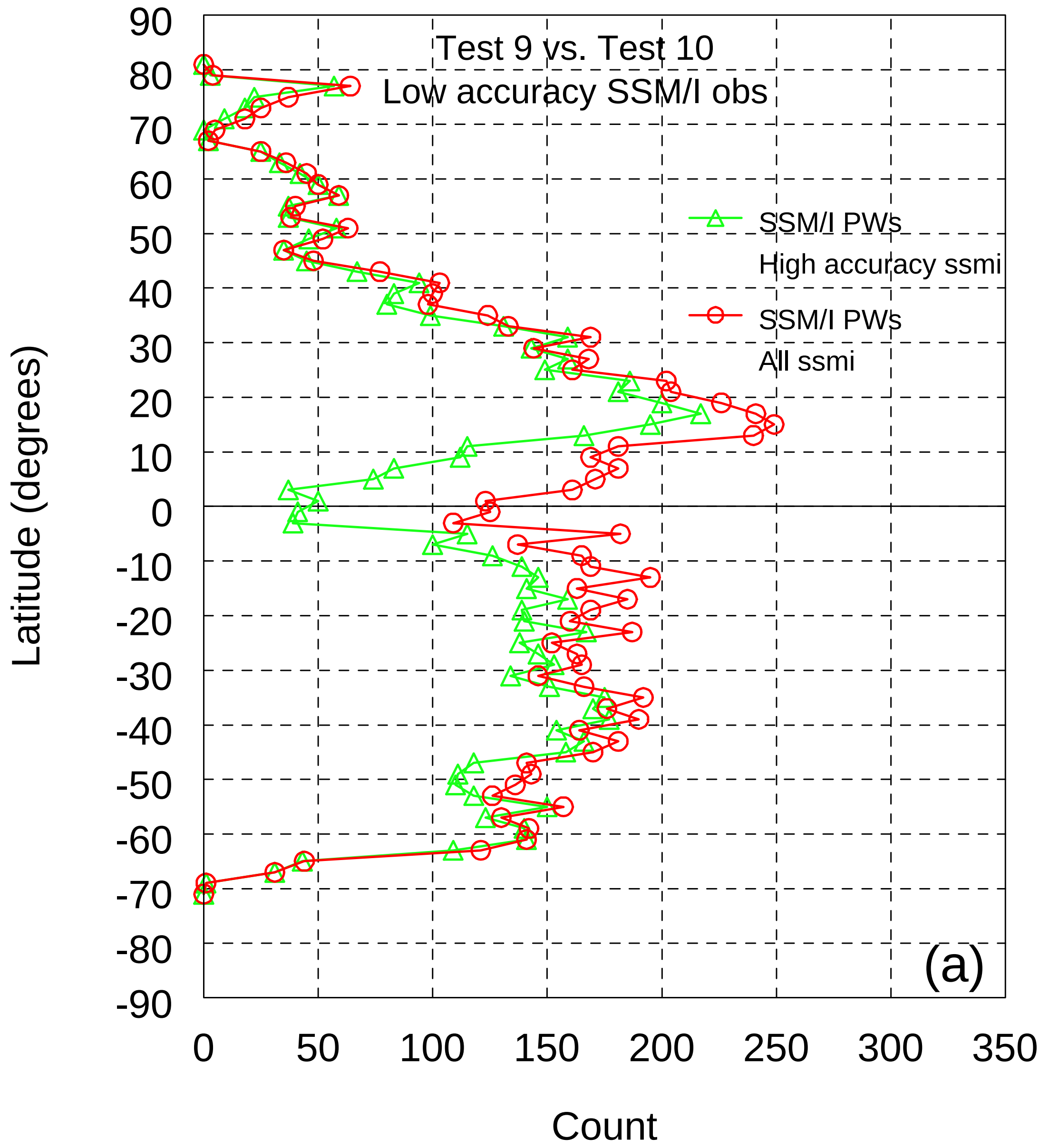


Figure 32: Same as Fig. 8 except for SSM/I precipitable water superobs with (red circles) and without (green triangles) low accuracy observations.

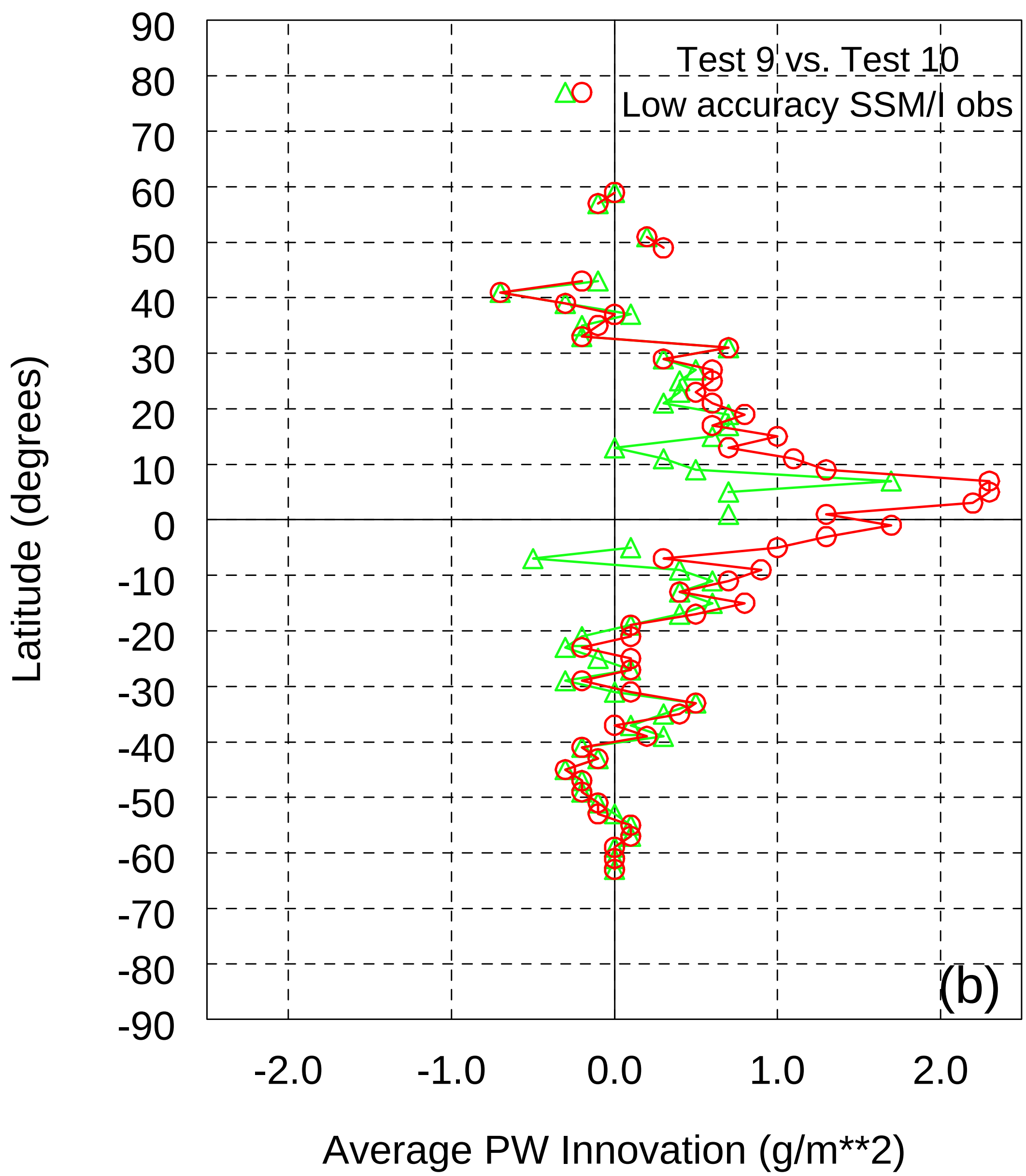


Figure 32: (continued)

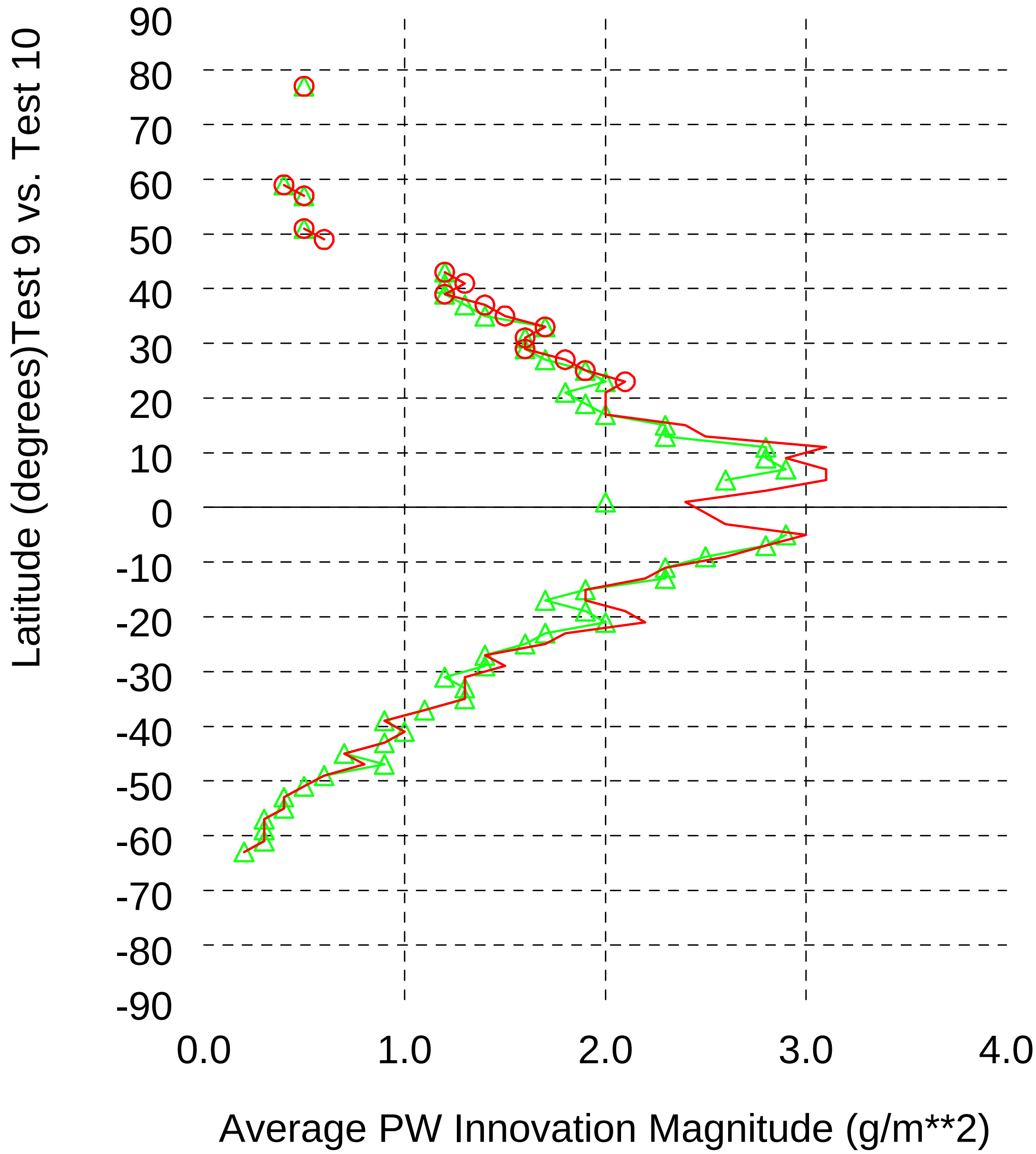


Figure 32: (continued)

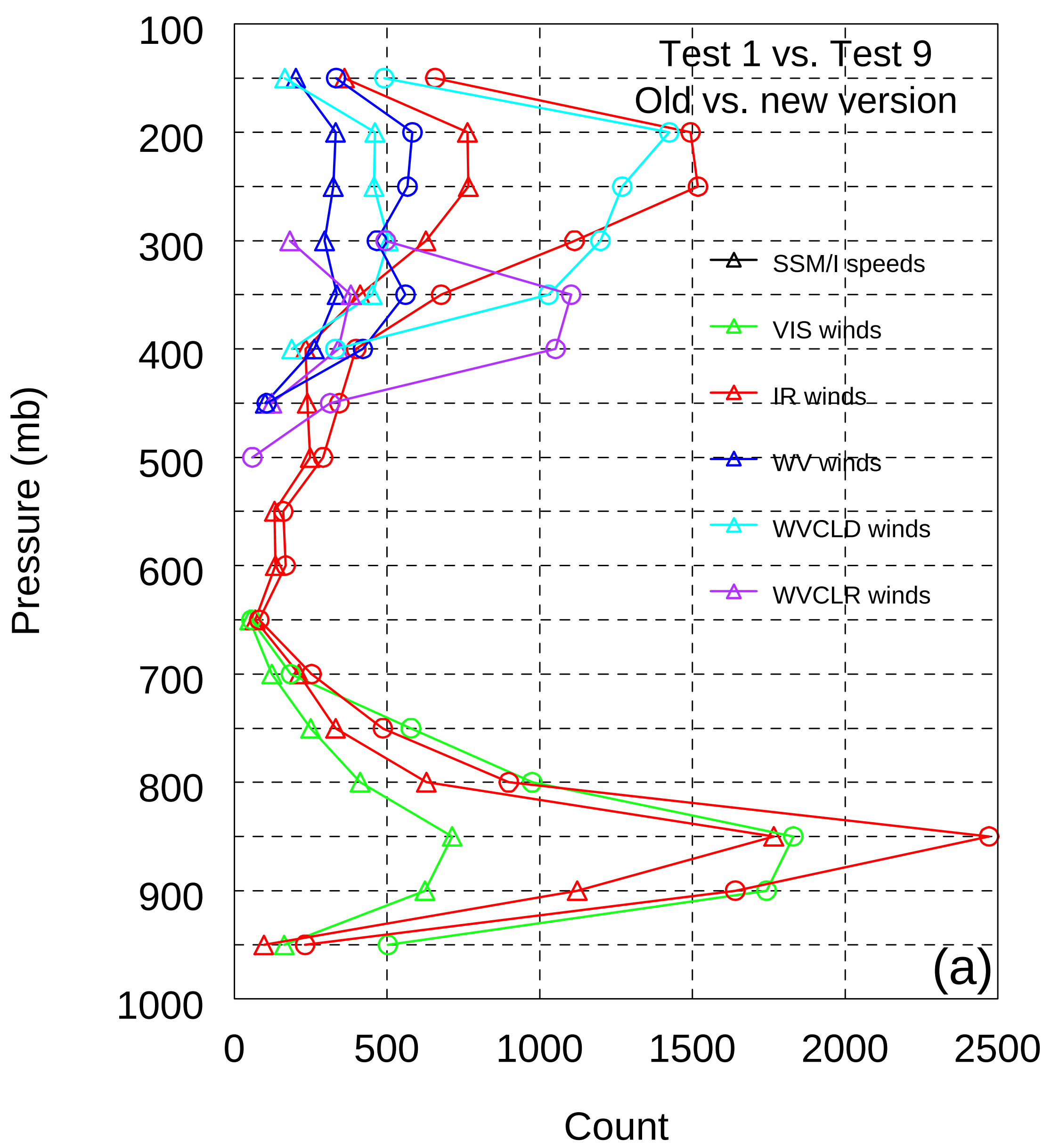


Figure 33: Same as Fig. 5, except superobs from Test 1 (old superob code) are shown as open triangles, and superobs from Test 9 (new superob code) are shown as open circles.

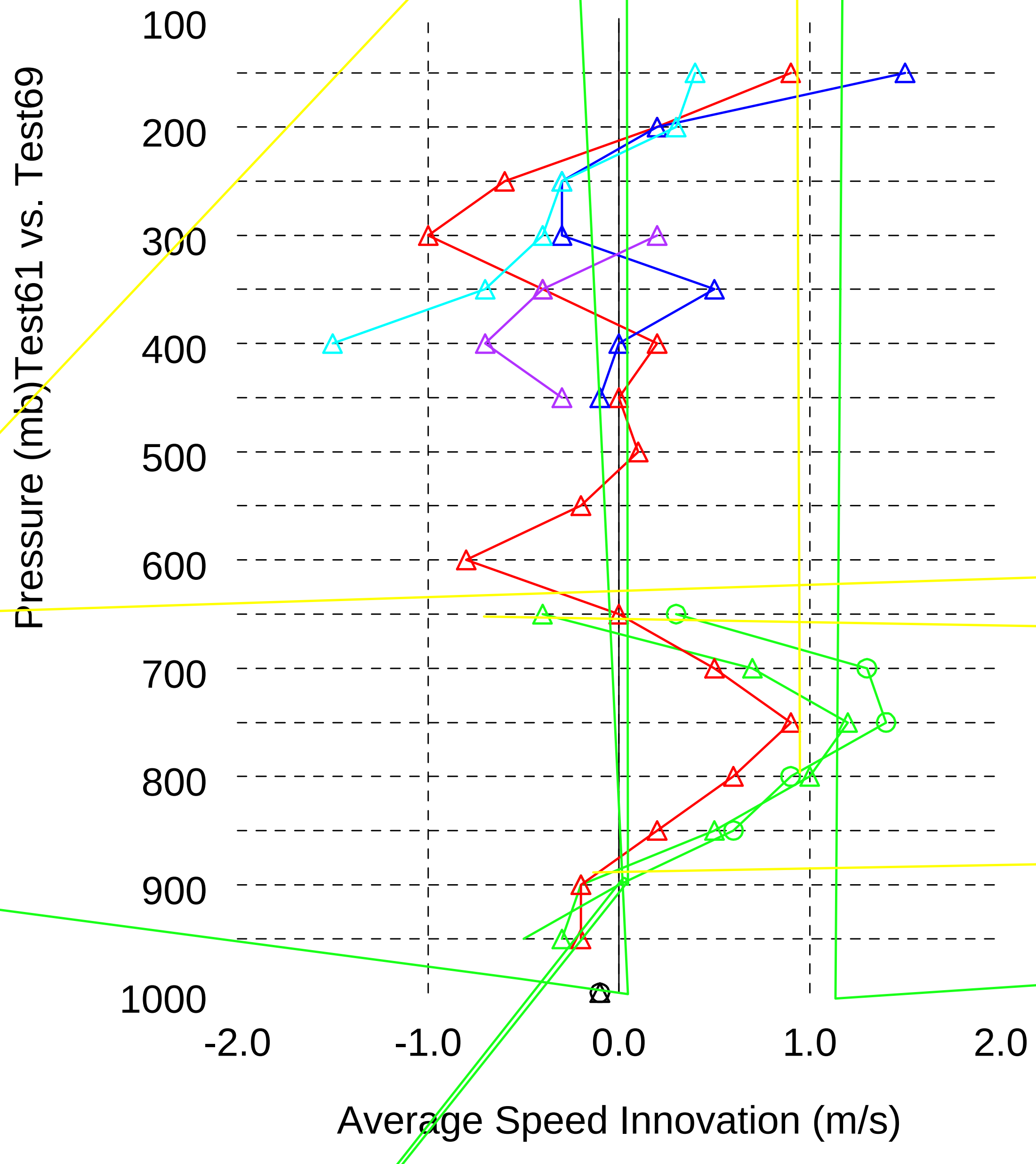


Figure 33: (continued)

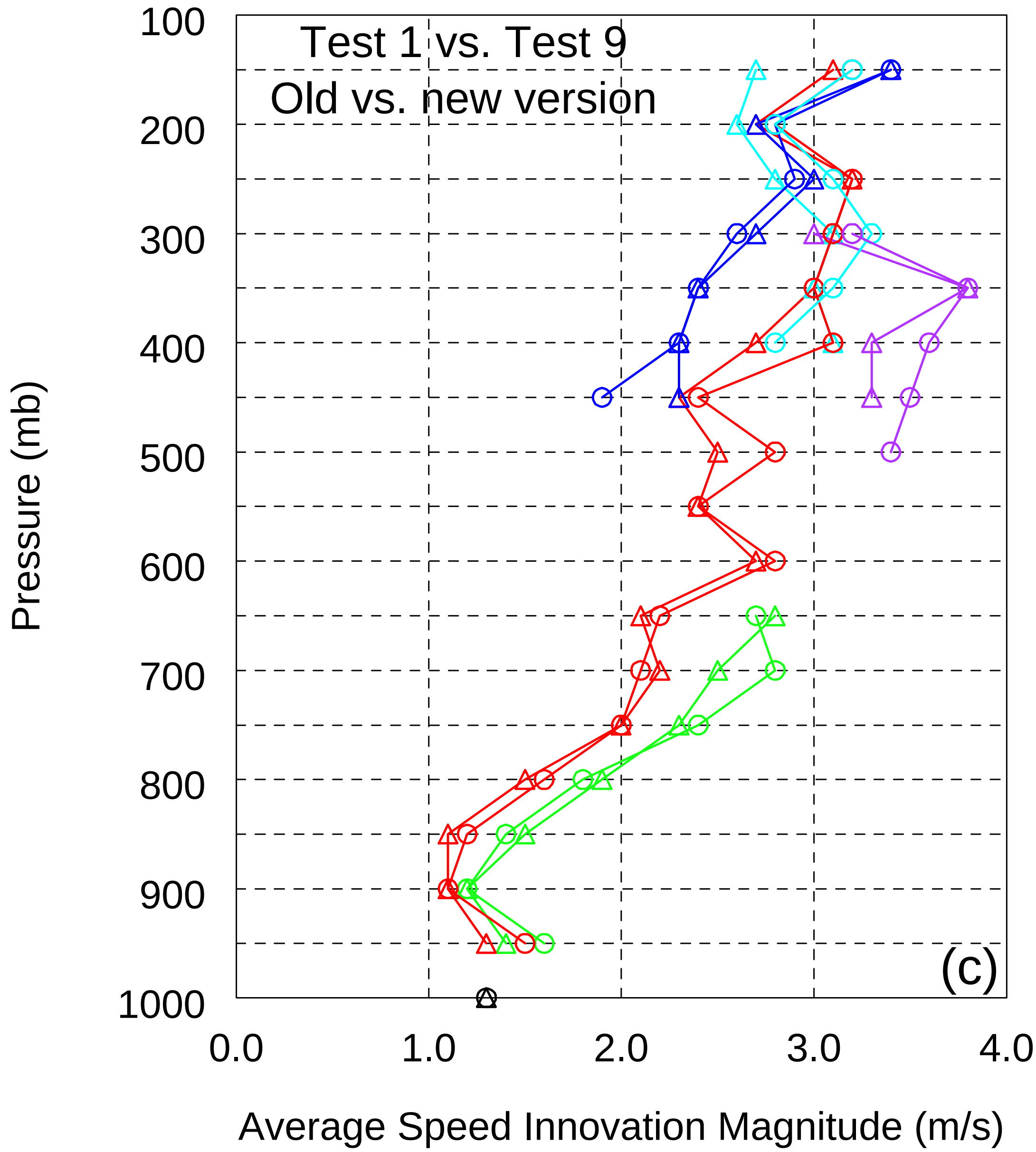


Figure 33: (continued)

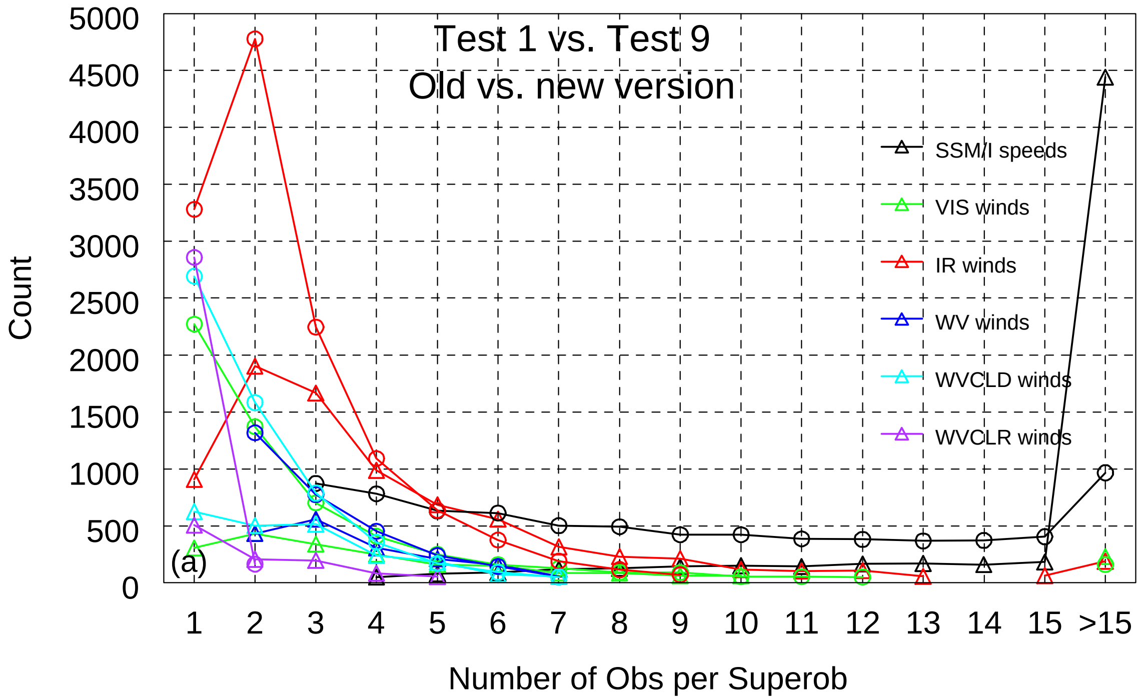


Figure 34: Same as Fig. 12, except superobs from Test 1 (old superob code) are shown as open triangles, and superobs from Test 9 (new superob code) are shown as open circles.

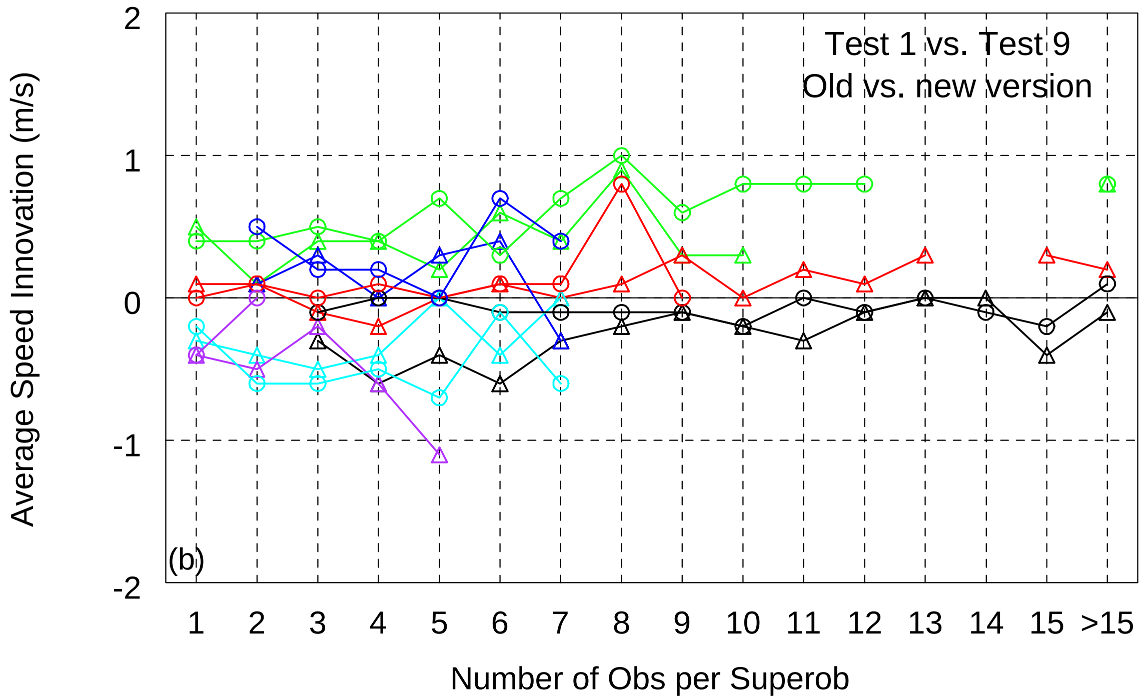


Figure 34: (continued)

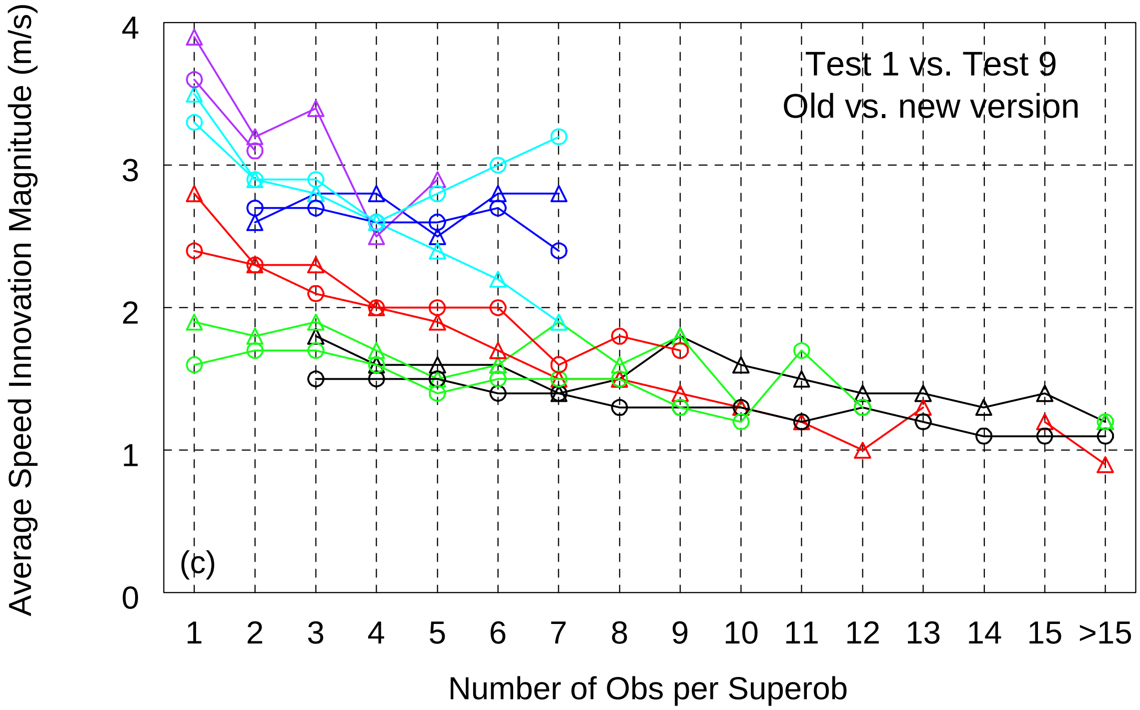


Figure 34: (continued)